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SURVEYS

CURRENT PROBLEMS OF AVIATION PHYSIOLOGY

[Article by N. M. Rudnyy and V. A. Bodrov]

[English abstract from source] Soviet aviation has developed an efficient system of medical support based on physiological knowledge and aimed at the solution of various problems associated with pilot selection and training, his professional activity, arrangement of his working place, etc. It is understood that the following lines of research hold great promise in protecting the human body against adverse flight effects: methods of protection against high altitude effects which also help maintain high operational efficiency; conditioning of transport, regulation and energy mechanisms of oxygen supply; methods of predicting man's tolerance to motion sickness; study of mechanisms of photoreception of blinding brightnesses; development of photoprotectors, etc. With respect to professional selection, it is important to use EEG data for prognostic purposes, to investigate lateral functions of paired organs, and to explore their relationship with body tolerance to flight factors and efficiency of training. The results of physiological investigations of the functional state of the pilot form the basis to standardize his workload, to develop rational work-rest cycles, and to prevent performance deterioration. Physiological recommendations can be used to formulate requirements for the configuration of the pilot working place.

[Text] Modern aviation is the most vivid expression of the achievement of mankind on the way to scientific and technological progress. All of the advances in development of aviation are attributed to the fact that it plays the leading role in solving national economic and defense problems of our country, and it is inseparably linked with science, basing its activities on basic and applied scientific developments.

At the present time, progress in aviation is being increasingly determined by man, by his role and place in systems of aircraft control and flight support. Physiological, psychological and professional capacities of man are the prime

factors that determine the success of performing flight assignments and safety of flights. The reserves for enhancing flight performance are largely found in man, and it is one of the principal tasks for specialists in various scientific disciplines and directions to find them and have them serve aviation.

Historically, from the moment aviation was conceived, studies of man during control of an aircraft were based on the physiological approach, on using the achievements of physiological science. The results of investigating physio- logical mechanisms of human adaptation to flight factors and working conditions served as the basis for many recommendations. The basic work of I. M. Sechenov, I. P. Pavlov, V. M. Bekhterev, L. A. Orbeli, V. I. Voyachek, I. P. Razenkov, M. Ye. Marshak, A. V. Lebedinskiy and many others hold a prominent place in aviation physiology.

At the present stage of development of aviation, advances in building aircraft, providing for effective and safe flights, as well as solution of the problem of flight longetivy depend to a significant extent on depth of investigation and fullness of using data concerning physiological patterns of interaction between man and aircraft, and effect on him of flight factors, information about psychophysiological distinctions of flight work, formation of professional skills. The inherent features of development of these and other problems of aviation physiology are, on the one hand, the increased practical relevance of results of physiological studies of support of flights and, on the other hand, achievement of a high level of theoretical generalizations and methodological developments in the area of aviation physiology, which make it possible to use them extensively in allied scientific disciplines.

Aviation physiology as a scientific discipline is a branch of general human physiology, and it interacts closely with such disciplines as industrial physio- logy, hygiene and psychology, engineering psychology, ergonomics, clinical physiology, etc. The tasks for aviation physiology are rather vast, and they are determined primarily by the requirements of medical support of efficient flight performance and flight safety, as well as distinctions of professional performance of individuals who work in aviation (flight personnel, air traffic controllers, engineering and technical workers), conditions and organization of their work.

The main directions of these studies are determined by the distinctions of flight work, and they are aimed at assuring efficiency and health of flight personnel by means of optimization of working conditions and organization of work, intro- duction of special means and methods of controlling the functional state, etc.

At the present time, a system of medical support of pilot work capacity and maintenance of pilot health has been formed in Soviet aviation and it functions rather efficiently; it is largely based on advances in aviation physiology. It provides for professional medial and psychological screening of flight personnel, development of psychophysiological recommendations concerning the education and training process, as well as ways and means of monitoring the level of prepared- ness, validation of recommendations on scheduling flight work on the basis of investigation of the functional state of flight personnel during flights and in the recovery period.

Elaboration of recommendations dealing with dynamic medical monitoring was an important result of studies of functional state of flight personnel on the ground and in flight. Determination of physiological, mental, anthropometric and other capacities of man interacting with aviation equipment serves as the basis for recommendations on operating equipment and laying out work places for flight crew members. Measures to provide protection against the adverse effects of flight factors, which consist of working out medical requirements as to special gear, clothing, rescue and survival equipment on the basis of investigation of the body's compensatory and adaptive capacities, distinctions of adaptation to flight factors, have been traditional in medical support of flights.

The need for further refinement of the system of medical support of flights due to the nature of development of aviation equipment and distinctions referable to its use determines the directions and content of investigations in the field of aviation physiology.

The inherent distinctions of flying work include exposure of pilots to a number of specific flight factors. For this reason, the main directions of research in the area of aviation physiology are investigation of compensatory and adaptive capacities of pilots, demonstration of distinctions of their adaptation to flight factors, validation and development of ways and means of protecting them against the adverse effects of these factors.

As before, the problem of furnishing oxygen to crews during high-altitude flights is one of the most important ones to aerospace medicine, since flights in the stratosphere and space are always related to the risk of development of pathological states, primarily acute hypoxia and altitude decompression sickness [caisson's disease]. In this regard, the efforst of specialists in altitude physiology are directed primarily toward developing the means of protection against oxygen shortage and low barometric pressure.

The optimum oxygen level at different altitudes is obtained when there is close to baseline oxygenation of blood and tissues with use of appropriate protective means. Combined investigation of the dynamics of functional state of the body's principal systems and work capacity revealed that a specific means of oxygen supply corresponds to a specific level of reserve capacities of the body, including capacity for performance of professional work. This is achieved in flights at any altitude with use of a pressurized cabin and pressure suit as protective factors, and with use of oxygen without positive pressure at altitudes of up to 10 km.

The results of investigations revealed that, with moderate hypoxia (pO_2 55-60% of baseline), there is some tension in the basic physiological systems, but the ability to perform operator work for a long period of time is retained; such a level of oxygen in the body is provided by breathing oxygen at altitudes up to 12 km without positive pressure and at altitudes of 30 km or more with positive breathing pressure.

In the case of marked hypoxia (pO_2 30-35%), there is significant tension in respiratory functions and hemodynamics, with decline in volume and quality of work performed. If oxygenation decreases to 25% of the baseline, there is marked stress and progressive impairment of basic functions, with appreciable worsening of performance.

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The method of supplying oxygen at high altitudes, which was developed in the late 1940's, by means of positive oxygen breathing pressure (30-150 mm Hg) has gained wide practical use. To date, there have been comprehensive studies of the mechanisms of changes and pathological reactions to such breathing. It was established that circulatory hypoxia, which develops as a result of deposition of blood in extrathoracic vessels, and difficult breathing are the main elements in the pathogenesis of disturbances. Compensation gear is used to prevent these disturbances.

However, it should be noted that altitude gear involves substantial discomfort to the pilot when he is at work, limiting working movements and range of vision, and worsening heat-exchange conditions. For this reason, it is an urgent task to develop means of providing the required level of protection against altitude factors with preservation of conditions for proper work by the crew.

With respect to the problem of hypoxic hypoxia, investigations of processes of faster adaptation to moderate altitudes by means of conditioning transport, regulatory and energy mechanisms of the body, as well as use of pharmacological agents, are promising.

In recent years, there has been an increase in attention to problems of physiology of accelerations, particularly in view of the increased piloting accelerations in certain types of light aircraft. Some researchers have indicated that there is a possibility of structural damage to the heart under the effect of high levels and long-term accelerations as a result of the gravity factor or because of development in blood of a high toxic level of catecholamines as manifestations of a stress reaction.

It is deemed quite important to explore the cumulative effects of high-level long-term accelerations, individual resistance to accelerations, mechanisms of compensation of functional disturbances under such conditions, etc.

In the area of aviation vestibular physiology, one of the important tasks is to elaborate more reliable methods of predicting man's resistance to motion sickness. One should continue the search for the most adequate ways and means of simulating the effect on the vestibular system of inflight accelerations. It is necessary to continue investigations for optimization of methods and criteria for differentiated vestibular screening of pilots in different types of aviation.

The increased power of modern aircraft has sharpened the problem of protection against noise. We imagine that the most important scientific results in this area of aviation physiology are related to determination of the significance of overstimulation of various mechanoreceptor zones of the body (primarily pulmonary and abdominal organs) in formation of adverse responses to extremely intense noise. The obtained experimental data permitted formulation of the principle of "total protection against superintense noise," which is applied in development of a new class of personal protection against noise--protective gear.

Several important problems arose in the area of physiology of vision in view of appearance of new principles for displaying information, increased velocity of visual flights, etc. We should include, first of all, investigation of contrast

sensitivity as related to different time and space characteristics of displayed signals, investigation of mechanisms of photoreception of blinding levels of brightness and search for photoprotective agents, investigation of distinctions of perception of collimator images.

In aviation physiology, there is an acute question of studying the combined effect of environmental factors on the body. In spite of the known difficulties involved in solving this problem, it is still the object of the closest scrutiny and investigation. In particular, it is interesting to study such consequences of exposure to some factors as stimulation of protective and adaptive mechanisms, which enhance resistance to other factors or, on the contrary, sensitization to these factors. It is rather important to have information about the role of the baseline functional state of the body, different systems, tissues and cells in development of the reaction to the set of factors.

Investigation of resistance of physiological systems and their adaptability to flight factors is aimed at finding the patterns of reactions that provide for high work capacity. But to predict the quality of pilot performance and maintain it at the required level by means of physiological recommendations, one must have knowledge about the laws of relationship between functional state of the body and human work capacity, laws of regulation of operator performance.

As applied to the problem of professional screening of flight personnel, at the present time there is the particularly urgent task not only of further improving methods of detection of latent pathology or functional disturbances, which are contraindications for flight work, but also of developing methods of assessing the state of rather stable and professionally important functions.

Electroencephalography (EEG) is one of the objective methods of testing the functional state of the human cerebral cortex; it has gained wide use in neurological practice and psychophysiological studies for both detection of latent organic brain lesions and functional disorders, and for investigation of individual psychophysiological distinctions. The EEG method is being adopted with success in the practice of expert medical certification of flight personnel and professional screening of cadets [or students].

At the present time, combined use of psychometric tests, personality questionnaires and EEG method is emerging to solve problems of psychological screening of applicants for flying schools [3]. For this reason, in addition to purely clinical evaluation of electroencephalograms, it is deemed promising to use the results of EEG analysis as well to determine the individual psychophysiological distinctions and predict training achievement.

Investigation of distinctions of functional lateralization of paired organs is one of the directions of investigating and considering the physiological and psychological capacities of an individual in the course of flight work. Interest in this problem is attributable to the fact that 32% of the pilots involved to some extent or other in onset of flight accidents were left handed, as shown by findings of foreign specialists, whereas they constituted only 5-7% of all pilots. It is also known that the arrangement of instruments and controls in the aircraft cabin is laid out with consideration of convenience for pilots who are right-handed and who have a right dominant eye, whereas according to a number of

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authors about 30% of the adult population have left-sided lateralization or symmetrical functions of paired organs [6, 11].

Interaction between cerebral hemispheres has attracted the attention of many physiologists in view of facts that expand appreciably our conceptions of the role of interhemispheric relations in connection of time-related associations, interpolar transfer and storage of traces of training, spatial analysis and organization of emotional behavior.

A special investigation was pursued [4] in order to develop a method of defining the individual profile of functional asymmetry in flight personnel and of validating the possibility of using it for professional screening; as a result, it was establsihed, in particular, that 9% of the pilots are left-handed and ambidextrous, 25% have a dominant left eye or functional symmetry of the eyes, 24% have a dominant left ear for speech or functional symmetry of the ears. On the basis of a screening of cadets and flight personnel, a method was developed for calculating the coefficient of dominant hand function for quantitative expression of its lateralization and to set standard values for it. It was noted that in the groups of cadets and flight personnel, regardless of level of professional training, there was about the same number of individuals with indicators of functional symmetry and asymmetry, i.e., functional asymmetry of paired organs is rather stable in this professional group. This finding is consistent with the data of other authors concerning stability of functional asymmetry in individuals of a mature age [5, 7, 8].

Another important fact is that people with good tolerance to radial accelerations and hypoxia have a tendency toward increase in interpolar asymmetry with exposure to these factors, whereas those with low tolerance show a tendency toward decline of asymmetry. The data confirm the opinion of B. G. Ananyev [1] and other authors to the effect that marked laterlaization of functions in the cerebral hemispheres is instrumental in man's complete adaptation to environmental conditions and expands his mental capacities.

The ever increasing attention that must be given to problems of training flight personnel is attributable to the constant development of aviation equipment, expansion of methods of using flight vehicles, high requirements of precision and reliability of controlling them.

Among the many problems of physiology, one of the focal ones is that of training and conditioning, namely, investigation of physiological mechanisms of formation of professional skills and patterns of the process of controlling them.

Using the systems approach to analysis of vital processes and behavior developed by P. K. Anokhin [2], it was established that training is based on formation of new functional systems, which provide for optimum achievement of a useful result. A functional system is made up of dynamic mobilized structure on the scale of the entire body. Presence in the system of a well-refined internal operational architectonics expressed in physiological concepts by afferent synthesis, decision making, formation of acceptor of results of action, feedback, renders this theory a tool for practical use in studies pertaining to human performance.

Since the significance of signals that a pilot receives for control of actions to pilot a plane at different stages of flight changes appreciably, it can be assumed that the process of formation of a new functional system consists of singling out and making active use for regulation of actions and achievement of a useful result only of signals that are necessary to solve a concrete problem. Proceeding from these theses, a hypothesis was expounded according to which the methods of flight training should be instrumental in rapid formation of the sensory, mental, motor and autonomic elements of flying skill that are of greatest importance to the flight stage being worked at. Analysis of psycho-physiological distinctions of formation of flying skills made from these vantage points made it possible to establish that there is appreciable change in significance of different information, by means of which there is feedback about consistency between performed movements and goal, in the functional systems that are being formed for these purposes. When making a visual landing approach this feedback occurs mainly as a result of visual perception of ground-based reference points, which permit evaluation of direction and angle of glide. When engaged in aerobatics, much importance is attributed to perception of the dynamics of accelerations and strength applied to the control stick, which permit evaluation of the rate of angular movement of the aircraft.

Active and deliberate formation of associations between various sensory systems (the pilot uses them to gain information about conformity of his movements to the specified program), with use of specially developed methodological procedures, makes it possible to render controllable the process of formation of flying skills, i.e., to implement in flight practice the principle of problem-oriented training.

It should be noted that refinement of methods of flight training, conditioning and retraining pilots is largely determined by the advances in the study of physiological patterns and mechanisms of regulation of the process of skill formation. However, there are still many unclear elements in this branch of physiology. The intimate mechanisms of fixation, consolidation of traces in memory have still not been adequately investigated. There is still no agreement on the question of which factors are instrumental or detrimental to retention of these traces, whether forgetting is "atrophy due to nonuse" or "erasing" of learned material in the course of learning or performing another task.

According to the conception of P. K. Anokhin [2], the flow of feedback concerning current and end results of actions is the regulatory mechanism of afferent synthesis. Hence, it can be assumed that one can affect the practice process as a whole by altering the flow of afferent signals.

Experimental investigation of the role of enhancement of feedback in formation of flying control skills revealed that use of the cutaneous analyzer, to check the results, in addition to the visual and proprioceptive communication channel, reduces substantially the amount of practice required to form a skill.

Investigation of the influence of flying work on the functional state of a pilot in order to regulate his work is a traditional direction of studies in the field of aviation physiology. Physiological validation of suggestions dealing with the scheduling of flight work includes development of recommendations on intensity of work load, schedule of flight day, sequence and frequency of the basic work measures in the course of a day, week, month or year, ways and means of restoring the functional state, etc.

Setting flight work standards is one of the means of preserving health, a high level of performance and enhancing professional skill. Wise standards help the pilot develop firm piloting skills, enhances his general endurance during flights and reliability of his actions. Investigations pursued to work out flight work standards are based on physiological investigations of the dynamics of flight work capacity and signs of pilot fatigue.

Special investigations established that the functional optimum of reactions recorded during flight work could be a physiological criterion for the work load [10]. Upon reaching the optimum limit, pilots develop compensatory reactions that can be defined as either the "phenomenon of autonomic motor activation," which is inherent in conditions of unchanging flight mode, or as the "phenomenon of conservation," when the pilot deliberately controls, lowers the level of functional tension by altering the flight mode.

Other conditions being equal, the flight work load should provide for an increase or retention of professional skin and maintain the functional state of the pilot and his work capacity at a high level. Investigations have shown that pilot reliability diminishes with a small work load due to partial destruction or insufficiently formed glith skills and with a large load, the same happens due to development of fatigue. Any deviation of the flight work load both in the direction of increase and decrease in relation to the optimum is characterized first by functional tension and then by worsening of performance.

Organization of the work and rest schedule for flight personnel must be based on data characterizing not only the dynamics of quality and tension of professional performance in flight, but distinctions of the recovery period. Analysis of the dynamics of recovery processes in pilots enables us to distinguish the following forms thereof: current recovery, which occurs during work when switching from one type of activity to another; immediate recovery observed right after work; deferred recovery, which occurs in the course of many hours after work. From the standpoint of organizing activities, investigation of deferred recovery is the most important.

As a result of investigations, it was established that changes in level of activity of physiological functions in this period are undulant, and the extent and duration of this undulant pattern depend on the flight work load, time of start and end of the flight shift. For example, recovery processes following flights in the morning have the shape of a double-peaked curve: after a period of relative normalization of functional state 4-8 h after flights, there is a first wave of increase in physiological activity, and 16-20 h later (after sleep at night) there is a second wave. Following evening flights, the recovery processes present a one-peak curve with maximum change in physiological functions on the following morning.

When flight work is intense, situations arise rather often that require active regulation of the pilot's functional state. For this reason, one of the main tasks for aviation physiology is to develop ways and means of controlling the functional state. This problem is being solved in two directions. The first is related to investigation of physiological patterns of flight work with consideration of these data in the design of work places and equipment, means of work actions, standards referable to living conditions in the cabin, etc. The

second direction refers to ways and means of having a direct effect on the pilot. They include, first of all, individual scheduling of flight work, means of active recreation, psychosomatic self-regulation method, pharmacological agents and many others. Some of them (such as affecting biologically active points on the skin, electrostimulation of the myoneural system, etc.) require in-depth scientific development.

One of the main research problems in the field of aviation physiology is the problem of fatigue of flight personnel, which is related to decline of functional capacities as a result of performing a flight assignment, and it is manifested by worsening of efficiency and quality of performance. In all likelihood, one should make a distinction between the concept of "flight fatigue," which arises as a result of the effects of flight factors and performance of aircraft control, piloting, and the concept of "flight personnel fatigue," the cuase of which is a load that is related more to performance of preliminary tasks on the ground than the flight itself.

In studies of flight personnel fatigue of recent years, the conception of the need to record three groups of parameters to diagnose this state has gained a firm foothold: professional, functional and reserve capacities of the body [9]. However, this methodological principle has not yet gained appropriate implementation in practice in such investigations. This is largely attributable to the lack of standardized methodological procedures.

The use of physiological recommendations to develop aviation equipment has a long history. The efficacy of these recommendations for the design of life-support systems, work places and individual protective gear against various deleterious factors has long since raised no doubts. At first glance, the ways and means of using physiological data to optimize interaction between elements in the pilot-aircraft-environment system are not as obvious. This is attributable, to some extent, to the fact that the correlations between physiological functions, which are the basis of vital functions, and mental processes that determine purposeful work activity have not yet been sufficiently investigated. However, on the basis of generalization of the results of a number of studies, at the present time we can propose a conceptual diagram that shows the nature of changes in physiological functions and parameters of performance under the effect of some factor. It consists in essence of the fact that, as the force of a factor increases there is increase in reaction by the physiological system that maintains the level of regulation of functions of greatest relevance to the body. Analogous changes occur in the structure of performance: at the expense of certain parameters that are secondary to the purpose of a given activity, its basic parameters are maintained at a rather high level. The eterioration of basic parameters of performance should be considered the most relevant pattern only after the leading physiological function changes to a new, reserve level of regulation. Of course, this scheme reflects patterns that are idealized to some extent. During actual performance of activity, other patterns could be "superimposed" over the former, related for example to the effect of getting into the swing of the task or a "last dash."

However, the following corollaries of practical importance ensue from the above relations: to monitor the pilot's state one must know expressly which systems and corresponding functions will be compensatory and which will be stabilizing as related to the factor involved; special recommendations referable

to engineering psychology could be used as means of compensation of changes in the structure of performance. For example, in view of the fact that emotional tension leads to "narrowing" of attention, it was proposed that indicators built into the basic instruments be used to signal malfunctions, and as a result there was dramatic decrease in time required to detect malfunctions and in probability of error.

In conclusion, it should be stressed once more that at all stages of its development aviation physiology based itself on achievements in alliked sciences, primarily physiology and psychology. Aviation physiology makes good use of the results of basic research in general physiology and psychology of higher nervous activity. For us, the following are of special importance: the teaching of I. P. Pavlov on conditioned reflexes and physiological mechanisms of human behavioral activity; theory of functional systems of P. K. Anokhin; conception of N. A. Bernshteyn conerning the leading and background levels of control of movements; conceptions of N. P. Bekhtereva about dynamic localization of functions and neurophysiological mechanisms of brain activity. On the other hand, aviation physiology has enriched science with important facts and results, which are instrumental in development of a number of physiological conceptions and theories. Aviation physiology as a scientific discipline is playing a perceptible part in effecting ties between science and practice, in solving many practical scientific problems of development of aviation, providing for flight safety and longevity in flying work.

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PROBLEMS OF ASSESSING HUMAN FUNCTIONAL CAPACITIES AND PREDICTING HEALTH STATUS

[Article by S. G. Salivon]

[English abstract from source] This paper reviews reports submitted to the First National Conference "Assessment of Human Functional Abilities and Health Prediction." Emphasis is placed on a systemic approach to the study of the functional abilities of the healthy man and prediction of his health status which takes into consideration interactions in the man-environment system and hierarchical patterns of the regulation of various functional systems. This approach makes it necessary to determine criteria of health as applied to different age and occupation groups, to study professional adaptation of different groups, and to clarify pathways of optimization of their work. It is important to examine specific features of regional adaptation, taking into account geography, climate, economy and social characteristics as well as migration patterns of the population; evaluation and prediction of health and functional abilities of man in a modified state or working in an unusual environment. It is equally important to develop methods of maintaining, restoring and increasing man's functional abilities and health; to develop automatic systems of assessing and predicting these parameters in view of the requirements placed by mass-scale medical examinations.

[Text] The intensive development of industry, science and technology, the rapid pace of life in a modern society have advanced the problem of the human factor to one of the most important places. At the present stage of social development of our country, the role of this factor is growing immeasurable in political, social, economic and cultural aspects. For this reason, the urgency of the problem of assessing man's functional capacities and predicting his health status is also growing.

At the First All-Union Conference on "Problems of Assessing Man's Functional Capacities and Predicting Health," which convened on 3-5 December 1985 in Moscow, there was comprehensive discussion of methodological approaches to the problem

of evaluating, predicting and controlling man's functional capacities and health. There was wide discussion of questions dealing with concrete criteria, methods and equipment for assessment of man's condition and automation of scientific research. Prominent scientists of our contrary, staff members of 97 scientific and scientific-practical institutions in all Union republics participated in the work of the conference, which was organized by the USSR Ministry of Health, USSR Academy of Medical Sciences and Institute of Biophysics of the USSR Ministry of Health. More than 300 plenary, section and poster papers were delivered and discussed at the sessions.

In his opening remarks at the conference, Ye. I. Vorobyev, chairman of the organizing committe and first deputy USSR health minister, observed that, as a result of major socioeconomic measures of the party and government to improve the welfare of the Soviet people and strengthen Soviet health care, some significant positive changes have been achived in the matter of disease prevention and improving the health of the people of our country. Further work in this direction requires comprehensive investigation of both man's health status and his functional capacities. This task is of theoretical and practical importance in order to define objective criteria for human health and disease, to assess and predict health status and functional capacities under both ordinary conditions and with exposure to extreme factors, to validate methods for increasing man's functional capacities and strengthening his health, to provide for complete occupational adaptation of different population groups under industrial and ecological conditions.

Ye. I. Vorobyev characterized primary prevention as a set of scientific organizational measures directed toward evaluation, prediction and control of functional capacities, work capacity and occupational adaptation of healthy man under the conditions prevailing in modern industry.

In his speech, L. A. Ilyin, vice-president of the USSR Academy of Medical Sciences and academician of the USSR Academy of Medical Sciences, dwelled on the main objectives of hygienic research dealing with the problem of assessing and predicting health, means of enhancing functional capacities of both the individual and population as a whole. These studies should direct themselves primarily to investigation of mechanisms of man's interaction with environmental factors, search for criteria, methods of evaluation and prediction of functional capacities, evaluation of the combined effect of environmental factors and the work process on public health, determination of quantiative functions of the dose-time-health status type. The solutions to these problems will be the basis for development and refinement of theory and practice of setting hygienic standards.

Papers were delivered at plenary sessions of the conference that dealt with a number of priority directions of development of Soviet health care.

Yu. P. Lisitsyn, corresponding member of the USSR Academy of Medical Sciences, provided a theoretical definition of public health as the properties of a social organism such as a community of people, its integral quality. This definition permits formulation of the question of science dealing with preservation and strengthening of public health and its reproduction—sanology—as a task for a developed socialistic society.

The paper delivered by Professor A. K. Guskova assessed the possibilities of using clinical observations of health status to detect and predict changes that occur when one changes to new living conditions and work. Mathematical approaches were described for determination of optimum range of normal variability and allowable incidence of different changes in healthy status. Professor V. M. Akhutin submitted results of developing automated systems for assessing the functional state of an individual on a real time scale.

The paper of M. G. Shandala, corresponding member of the USSR Academy of Medical Sciences summarized data on determination of public health status as a quantitative function of nature and degree of expression of a set of environmental factors; the priority of different factors was established with regard to their effect on public health; there was scientific validation of recommendations on environmental protection and improvement. Professor V. V. Venediktov proposed a method of quantitative evaluation of characteristics of individual health status in heterogeneous cohorts, while Professor R. M. Bayevskiy offered a classification of functional states and assessment of levels of health from the standpoint of adaptation theory.

In assessing the immediate prospects of work on the problem of "Man's health status and functional capacities," Professor V. S. Koshcheyev validated the need to elaborate regional programs of research and implementation of large-scale sociomedical observations in order to create an All-Union program for this problem. Use of automated systems of scientific research is a mandatory prerequisite for its effective solution.

There was reflection of development of these issues at the section meetings.

For example, the methodological section discussed the norm as a "physiological syndrome." In particular, it was shown that various types of the norm, according to three groups of parameters (general, group, unique) are encountered in a specific combination in a healthy organism. This specific combination of types was defined as the physiological syndrome (I. A. Gundarev, Scientific Research Institute of Preventive Cardiology, All-Union Cardiological Research Center, USSR Academy of Medical Sciences).

A discussion that arose at the section dealth with the question of criteria for evaluation of health. It was noted that this parameter should be based not only on the "status norm," but on the "reaction norm" as related to different factors (including extreme ones). Such an approach is closely related to the question of man's adaptive capacities. Most speakers voiced the opinion that one can assess the health status of man by studying his functional capacities. And it is important to elaborate criteria for assessing the different functional systems of the body on different hierarchic levels of organization in order to accumulate a data bank pertaining to healthy man. At the same time, it was stressed that it is necessary to make an integral study of man and obtain integral information about his functional state.

Much attention was devoted to various combined approaches to assessment of health. In particular, there was discussion of the biorhythmological approach to evaluation of man's functional capacities on the basis of the relations that exist between phenomena of human adaptation, homeostasis, work capacity

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and circadian rhythms (B. S. Alyakrinskiy, G. M. Divert and G. M. Domakhina, M. K. Chernyshev). It was suggested that health status be assessed quantitatively by the energetic, plastic and regulatory reserves for implementation of functions (G. L. Apanasenko).

The approach described by S. A. Dushanin for evaluation of functional capacities of man according to five independent factors is of definite interest; he refers to capacity, force, mobilizability, economy and feasibility of potential capacities characterized by criteria that have been elaborated. On the basis of this approach, four categories of the norm were singled out: minimal, for differentiation between physiological and pathological states; norm of the vast majority to characterize mean values in a large population; the ideal for expression of optimum values with respect to providing for man's resistance to environmental factors, and special norm, expressed in values required for performance of different social tasks involving high demans of functional and metabolic biocybernetic systems.

Discussion of the concepts of "health" and "norm" revealed that there is still no agreement on this score. This shows that there must be consolidation of efforts of different specialists in order to define these concepts and elaborate quantitative criteria for them.

At the clinical section of the conference, questions of norms as applied to human health were the topics of the papers of A. K. Guskova, S. A. Keyzer, D. M. Zlydnikov and O. I. Kubar. It was recommended that a distinction be made of four groups for enrollment for dispensary observation: essentially healthy, risk group, premorbid and disease groups.

The work of one of the sections was concerned with questions of correction of functional state and individual protection of people whose work is characterized by large physical and psychoemotional loads, and not infrequently is performed under extreme environmental conditions. In essence, there was discussion of the matter of controlling man's functional capacities by different methods and means--physiotherapy (Ye. A. Tarasov, R. A. Durinyan and M. A. Vasilenko, B. P. Prevarskiy et al.), psychotherapy (V. S. Chugunov et al., T. N. Azarenkov et al.), pharmacological (Yu. G. Bobkov et al., M. A. Gerasyuta), as well as personal protective gear (Yu. N. Sosenkov et al., Ye. P. Tikhomirov et al., A. S. Yarov et al., M. I. Kharchenko et al.). It should be noted that the papers were both of a theoretical and applied nature, focusing on the problem of preserving and restoring health, enhancing labor productivity and athletic achievements (A. V. Lupandin, A. G. Rumyantseva et al.). The need for a combined solution to these problems was stressed in discussions of the papers.

Opening offices at industrial enterprises for psychological unwinding and medical rehabilitation complexes, which constitute a unique psychological "antienvironment" in relation to industrial premises and thus have a positive neuropsychological effect on visitors, has become one of the directions of practical implementation of advances in the area of controlling man's functional capacities (V. S. Kartsovnik et al.). The entire structure of the offices and complexes serves for this purpose, including their decoration, equipment, lighting, color scheme, acoustic, climatic and esthetic elements of the environment. In such complexes, rehabilitation measures are implemented, such

as water procedures (pool, sauna, baths), relaxation and breathing exercises, aerobics, exercising with special equipment, simulators; oxygen cocktails are used, as well as methods of group psychotherapy and audiovisual therapy, autogenic training, reflex therapy, etc. In the discussion of the results and prospects of using pharmacological agents (including adaptogens) to optimize the functional state of a healthy man, it was noted that there must be strict limitation of the area of their application.

It was learned through the discussions that preventive medicine is presently armed with a vast arsenal of agents capable of specifically and selectively influencing processes that determine man's health and of controlling his functional capacities.

The work of the section on psychophysiological aspects of the problem was concentrated on two basic directions: search for approaches to evaluation and prediction of psychological adaptation and human health under ordinary and adverse working conditions; determination of means of enhancing functional capacities and psychophysiological reserves of healthy man.

The delivered papers and discussions dealt with a wide range of methdological problems and the results of concrete investigations.

The paper of Professor F. B. Berezin inspired the greatest interest; it was concerned with analysis of psychophysiological mechanisms and relations in the system of providing for health and efficient performance. He summarized the results of many years of investigations pursued by a large team of the patterns of human psychological adaptation, including adaptation in regions with a rigorous climate; he demonstrated convincingly the importance of studying mental adaptation to evaluation and prediction of man's health and effective performance.

The paper of M. A. Lartsev and L. V. Morozova submitted interesting data on the correlation between distinctions of psychological adaptation and immunoresistance on the example of the participants of a high-latitude expedition of the newspaper, KOMSOMOLSKAYA PRAVDA, involving arctic passages. The results of a study of factors causing a state of psychological deadaptation and questions of predicting human deadaptation under extreme conditions were covered in the papers of V. A. Varlamov and M. I. Maryin et al.

The conference participants observed that future psychophysiological research on this problem should involve expansion and deepending of a unified conceptual and methodological, multilevel, systems analytical approach; more attention must be given to investigation of psychological adaptation of healthy people, particularly those working in regions of the North, North East and arid zone, with elaboration of population norms according to concrete psychophysiological characteristics. There must be intensification of studies of psychophysiological aspects of distinctions in interactions and functional capacities and health of individuals who use computers, as a section of a new scientific discipline that is at the formative stage--informative hygiene.

The section entitled "Functional State of Man and Professional Performance" discussed two directions of research on this problem: functional state, functional

reserves and human efficiency in professional performance; effect of the increasingly complicated and diverse nature of professional activities on man with his individual and species-specific distinctions and functional capacities.

At the section meeting, much interest was inspired by papers dealing with methodological problems of assessing functional state and functional reserves of working man (A. N. Medelyanovskiy, L. A. Reshetyuk, G. L. Strongin). The question was raised of creating a language for communication and unified terms for definition of reliability of operators and their work capacity.

The discussions noted the timeliness of issues raised in the section, the need to continue work begun to develop unified methods of investigation and instrumentation (Z. K. Sulimo-Samoylo, V. P. Grebnyak and others).

The papers delivered in the toxicological section dealt with such problems as the combined and integrated effect of environmental factors (various chemicals, altered air temperature, noise, vibration, etc.). Several papers discussed development of hygienic regulations for toxic agents, evaluation of their effects on man and determination of functional reserves as related to route of intake of toxic agents.

Of greatest interest were the papers of G. I. Sidorin, Yu. N. Stroykov and L. V. Lukovnikova dealing with establishment of informative parameters of human functional state with exposure to toxic substances. There was discussion and approval of toxicological hygienic approaches to regulating toxic agents in the environment; it was noted that some advances have been made in the study of mechanisms of interaction between the human body and various factors. It was stressed in the discussion that it is necessary to determine the common patterns in the effects of chemical agents in order to establish the quantitative function of concentration-time-effect.

In the section entitled "Functional State of Man and the Environment," there was discussion of the most urgent aspects of the problem of assessing functional capacities and predicting the health status of workers in different sectors of the national economy. Much interest was inspired by the paper of N. G. Karnaukh, F. A. Shleyfman and Ye. R. Dorokhin which dealt with sociomedical aspects of health status of workers in the metallurgical industry, as well as the paper of M. A. Mironenko concerning parameters of rural public health status as a quantitative function of the state of the environment. The papers and poster reports represented not only experimental and theoretical analysis of functional capacities and health status of a number of occupational groups, but hygienic recommendations that have already been adopted, which have improved significantly working conditions and health status of workers.

Discussion of mathematical approaches to evaluation of public health, as well as results and prospects of using automated systems to assess the body's functional state and diagnose diseases occupied a significant place at the conference.

Development of automated systems of scientific researcy (ASNI), based on use of computer engineering, should now be considered one of the powerful means of increasing labor productivity in medical science and practice, and consequently

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of accelerating development of research and adoption of its results. E. P. Popov and V. A. Lishchuk discussed in their papers questions of interaction between physicians and modern ASNI.

Use of ASNI in health care would help solve problems of processing large volumes of measurement information, controlling the progress of clinical tests, gathering and accumulating data, ongoing comparison of results of investigations to patient histories, plotting graphs and writing up medical conclusions on the basis of specialized data banks, in which there would be automatic accumulation of results of, for example, mass-scale examination of employees of an enterprise. Expert systems, which are being developed in recent times, could be used in the ASNI banks, and this would permit automation of diagnostication with a high level of reliability.

Some interesting work on development of automated work places for physicians was reported by representatives of the Riga Health Department (V. A. Savin). In the future, the polyclinic physician is seen in his office at the screen of a display on which he can call virtually instantly for any information about his patient's health status, rather than buried by piles of polyclinic cards.

In the recommendations made by the conference, it was stressed that it is imperative to elaborate a systems analysis approach to the study of functional capacities of healthy man and prediction of health status, which would take into consideration the relationships in the man-environment system and the multilevel nature of control of the body's functional systems. There must be a definition of health criteria for different rage and occupational population groups; studies must be pursued of the distinctions of occupational adaptation of different population groups, and there must be validation of the means of optimizing the work process. It is important to study the distinctions of regional adaptation, with consideration of the aggregate of climate, geographic and socioeconomic conditions, as well as selectivity of the migration flow, evaluation and prediction of health and functional capacities of man with altered functional state, as well as his functional reserves when working under adverse conditions. There should be validation of the means of preserving, restoring and enhancing functional capacities and health; automated systems should be developed to assess and predict functional state and health as related to questions of universal dispensary observation of the public.

EXPERIMENTAL AND GENERAL THEORETICAL RESEARCH

RELATIONSHIP BETWEEN INFORMATION AND ACTIVATION, AND MENTAL WORK CAPACITY OF OPERATORS

[Article by K. K. Ioseliani and B. N. Ryzhov]

[English abstract from source] This paper presents the results of studying diagnostic potentials of the method used to assess mental performance of operators based on a combined application of the information carrying capacity and psychophysiological expenditures of man. Three groups of operators (45 subjects) that differed in their health status and motivation when performing sensorimotor tests were examined. Psychophysiological cost was measured with respect to autonomic responses (heart rate, respiration frequency, minute respiration volume, arm temperature) combined into an integrated parameter of psychic stress. It was found that the extremums of the relationship between information and activation parameters were invariant. The data obtained suggest that the information-activation relationship may be used to advantage in the clinical and physiological expertise of operators.

[Text] Evaluation of mental performance using modern psychodiagnostic load tests often leaves open the question of the extent to which the results are attributable to the concrete test situation and to what extent they reflect the potential capacities of an individual to perform a task with a specific degree of efficiency [3, 7, 8, 11, 12].

It is quite difficult to answer this question, since it is virtually impossible to form a state in the subject that would be adequate to his professional activity. The stress of the testing situation in some people and indifferent attitude toward test results in others diminish to an equal extent the value of the obtained data and worsen the possibility of interpreting them. One of the means of solving this problem may be to use combined evaluation of efficiency of operator performance, which includes psychophysiological assessment of the functional state, in addition to productive parameters of performance. Use of such evaluation makes it possible to move from analysis of absolute values for information carrying capacity to analysis of its specific increments obtained with consideration of the psychophysiological cost of the activity performed. Practical implementation of such combined assessment of efficiency has

been facilitated by development at the present time of formalized methods of analyzing operator performance, which permit evaluation of carrying capacity and functional state in unified reference systems, regardless of the concrete set of parameters studied [1, 2, 4, 6, 10].

We have tried here to investigate the diagnostic potential of a method of combined evaluation of operator efficiency in a group of individuals in flight occupations who underwent an in-hospital clinical and psychological screening to determine their subsequent professional fitness. It was assumed that use of this method would permit detection of the specifics of changes in work capacity while performing a test assignment under conditions differing in difficult, and to obtain an evaluation of work capacity level regardless of the subject's emotional state.

Methods

A total of 45 operators participated in this study, and they were divided into three groups according to health status.

The 1st group consisted of 15 people who were referred to the hospital for examination because of moderate functional disturbances in their health status (long-term sequenlae of mild closed cerebrocranial trauma, neurocirculatory dystonia, vegetovascular instability, etc.); the 2d consisted of 12 operators with more marked somatic disturbances in the form of grade I essential hypertension, gastritis, early signs of ischemic heart disease and others.

The control group (3d) consisted of 18 essentially healthy operators with no diagnosis, who were referred for the clinical and psychological examination in connection with appearance before the medical board for flight personnel.

It was established from the history and on the basis of observation of operator behavior prior to the start of the examination that all individuals in the control (3d) group and most of the subjects in the 1st group were actively anxious to pass the expert tests well, since the conclusion they receive from the examination is one of the criteria for determining their subsequent professional fitness.

In contrast, representatives of the 2d group presented significant decrease in interest in having positive results from the expert clinical and psychological examination.

Thus, the preliminary data are indicative of different levels of motivation in the groups of subjects. At the same time, the similar age (27-38 years) and qualifications, mild nature of diseases of the operators and adequate statistical representativeness of the groups did not offer any grounds to predict appreciable intergroup differences in work capacity.

We used one of the variants of the method of "giving answers at a specified pace" as a load test, it is currently used for psychological diagnostication of flight personnel [5]. The subject was placed before an instrument that had 10 indicator lamps on the front panel and the same number of keys, which corresponded to the lights and which he was to depress as the appropriate

light went on. We used five modes of displaying information which differed in speed (i is the sequential mode number). The time between two flashes (T_i), which determined the pace, varied from 1 s for the minimal mode to 0.4 s for the extreme one; the number of the light that was to flash was selected according to the law of random numbers, and total working time in each mode was 2 min.

To assess the difficulty of the work modes for each operator, we calculated the intrinsic speed of presenting information (H_i) determined in accordance with the Hartly formula [10]:

$$H_i = \frac{1}{T_i} \log_2 K \tag{1}$$

where K is the quantity of independent symbols at the input (10).

We used the operators information carrying capacity as productive parameter of work capacity and, considering possible operator errors, it was determined by the following formula:

$$I_i = \frac{1}{T_i} (\log_2 K - N_{er}) \tag{2}$$

where N_{er} is uncertainty due to the effect of operator errors.

Consideration of psychophysiological expenditures of the subject is effected on the basis of determining the integral parameter of stress for each work mode, which was based on combined analysis of data referable to heart rate (HR), respiration rate (RR), minute respiratory volume (MV) and temperature of the palmar surface of the left (nonworking) hand t_p^0. See [9] for a detailed description of the procedure for determining the integral parameter of stress.

Evaluation of efficiency of operator performance was made on the following assumptions: in the described task, efficiency of performance should improve with increase in carrying capacity; efficiency of performance, other conditions being equal, should decrease with increase in psychophysiological cost to the operator. In the simplest form, these requirements can be expressed as follows:

$$E = I \cdot (1 - G) \tag{3}$$

where E is a dimensionless parameter of efficiency of operator performance, G is integral parameter of stress, which changed, according to [9], from zero (absence of psychophysiological signs) to one (with maximum expression of these signs).

Statistical analysis of the results of 225 tests and processing of the results using equations (1-3) were performed on a EC-1030 computer.

Results and Discussion

As shown by the results of the tests, the level of psychophysiological expenditures presented an overt group determination with change in work mode (Figure 1). Analysis of special psychophysiological parameters revealed that HR and RR were proportionate to H in subjects of the 1st and 3d groups; an elevation of

the temperature response and increase in respiratory volume with increase in work pace were in the nature of a trend in these groups of subjects.

In the second group of subjects, a tendency toward elevation of parameters of psychophysiological functions was noted only when information was delivered at the rate of 4.15-6 bits/s. Further increase in rate did not lead to increase in tension, whereas with H = 8.3 bits/s there was even a relative decline in level of psychophysiological cost.
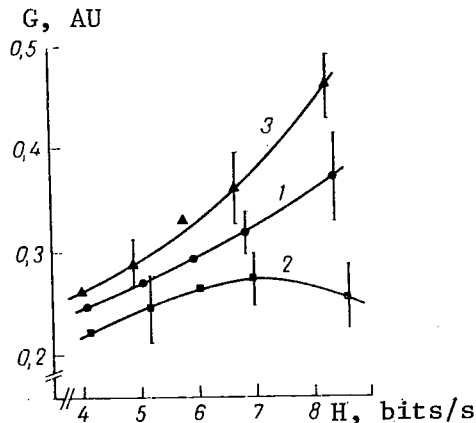
Figure 1.

Psychophysiological cost to operator as related to different speed of work

Here and in Figures 2 and 3:

      1-3) 1st-3d groups of subjects, respectively

      AU) arbitrary units
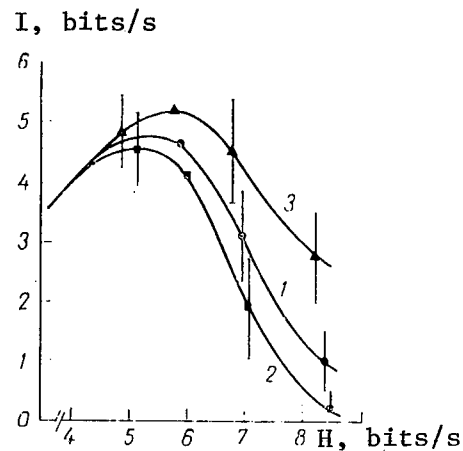
Figure 2.

Information carrying capacity as related to different work speeds

Intergroup differences in achievement were also rather great. As can be seen in Figure 2, the 2d group of operators coped well with their job at speeds of delivery of information not exceeding 6 bits/s, demonstrating a critical decline of reliability with further increase in speed. These operators virtually failed to cope with the job (probability of failure at H = 8.3 bits/s constituted 0.94 for the group as a whole) in the range of high-speed delivery of information. A decline in reliability with increase in work speed occurred much more slowly in the highly motivated groups of operators. With H = 6.91 bits/s more than 50% of the delivered information was processed correctly. It is only at maximum speed of delivery of information that probability of error rose to 0.67-0.89 in these operators, and it was associated with increased perspiration as well as behavioral and verbal reactions typical of emotional stress. With critical decline of reliability (below the 50% level), 75% of the operators in the 1st and 3d groups changed their working position: their torso was bent forward, closer to the instrument panel, their shoulders were raised and muscles of the limbs were tensed, as if getting ready to stand up. Many subjects, having forgotten that they were wearing the pneumotachometer mask on their face, tried to explain the cause of their mistakes to the experimenter. There were no behavioral or verbal reactions while performing the task in the 2d group of operators.

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Figure 3.
Efficiency at different work speeds

Analysis of operator efficiency revealed that the greatest intergroup differences in parameter E were noted with the maximum rate of delivery of information, i.e., at H = 6.91 bits/s; at this speed, standard deviation of efficiency parameter constituted 30% of the mean group level of E, and with H = 8.3 bits/s it was about 90%.

Efficiency of performance in the range of H = 5-6 bits/s was indicative of the fact that this parameter depended insignificantly 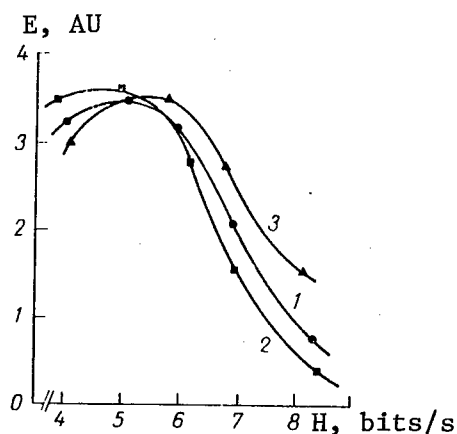on the level of the subjects' motivation (Figure 3). Under these conditions, intergroup differences in efficiency did not exceed 3-4% of the mean level of E, reaching an absolute minimum (about 1% of mean E) with delivery of information at the rate of 5.14 bits/s. It should be noted that the highest intragroup efficiency parameters were obtained at this speed.

Analysis of the results revealed that the changes in carrying capacity with increase in speed of delivering information were in the same direction in representatives of all groups, and they differed only in quantitative parameters. Conversely, the changes in functional state of the operators bore the imprint of qualitative differences: as shown by the test results, the increase in speed of performance of operations led to substantial increase in tension in subjects who initially had a high level of motivation; in the case of using critical speeds for delivery of information, which lowered achievement to less than 50%, the stress was markedly emotional. In subjects with a low level of motivation, we failed to demonstrate reliable differences in level of tension with change in working pace.

The observed tendencies were uniquely reflected by changes in the parameter of performance efficiency. Intergroup differences increased significantly with decrease in efficiency in the range of critical speeds of delivering information. At the same time, the higher baseline level of most psychophysiological parameters in highly motivated operators, as well as the greater efficiency of subjects in the 2d group with H = 4.15 bits/s (see Figure 3), enable us to expound a hypothesis, that appears paradoxical at first glance, to the effect that there is prevalence of parameters of efficiency in poorly motivated subjects in the range of slow rates of delivery of information (0-4 bits/s). Unlike the high-speed modes of work, with which the high efficiency of highly motivated subjects was consistently attributable to their greater productivity due to mobilization of additional resources, with relatively simple, low-speed performance one should expect 100% achievement in all groups. Under such conditions, the decrease in efficiency would occur due to excessive operator stress, inconsistent with the task at hand, and this can be expected with greater probability among highly motivated subjects in view of their interest in the test results and, consequently, the possibility of emotional reactions to the testing situation itself.

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Our findings, particularly the approximate equality of parameters of efficiency in all groups of subjects at certain work speeds, confirm the assumption that there are no reliable intergroup differences in mental work capacity in the tested group. At the same time, these data, which are indicative of the inadequacy of using productive parameters alone to evaluate work capacity, are indicative of the possibility of refining examination methods by using integral parameters of the described type.

The obtained results enable us to recommend 5-6 bits/s as the rate of delivery of information that is the most expedient for expert evaluation of individual level of work capacity referable to sensorimotor activity of operators. Under such conditions, the deviations of efficiency of function in relation to the mean statistical values can be interpreted as an indicator of an individual's capacity for adaptation, reflecting not only his carrying capacity but reliability of performance in information systems.

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DYNAMICS OF HORMONES, SUGAR AND ELECTROLYTES UNDER HYPODYNAMIC CONDITIONS ACCORDING TO BLOOD BIOCHEMICAL PARAMETERS

[Article by V. V. Makarovskiy, Yu. P. Reznikov, A. F. Khalangot, and S. A. Zinkovskaya]

[English abstract from source] Time-course variations in hormones, carbohydrates and electrolytes (specifically, cortisol, aldosterone, testosterone, T3, T4, sugar, potassium, sodium and chlorides) in blood of essentially healthy men, aged 19-59 years, kept for 30 days in a closed life-support system were measured. The hormones, sugar and electrolytes varied in a different manner. The subjects, aged 48-59 years, who performed regular exercises showed a higher stability of potassium, sodium and chlorides and a normalization of hormones by test day 30 in contrast to other groups of subjects.

[Text] Long-term hypodynamia as a result of limiting motor activity may have an appreciable effect on the endocrine system and, consequently, metabolism, intensity and nature of compensatory and adaptive reactions that occur in the body.

We submit here data pertaining to changes in levels of cortisol, aldosterone, testosteron, triiotothyronine (T3) and thyroxine (T4), sugar, potassium, sodium and chlorides in the blood of essentially healthy men who were submitted to hypodynamia for 30 days in a closed environment with constant parameters of temperature and humidity, as well as gas composition of air: temperature 20-24°C, air mobility 0.1-0.3 m/s, humidity 70-80%, carbon dioxide 0.3-0.6% and oxygen 19-20.8%.

Methods

The composition of the tested groups, conditions under which blood samples were drawn and mean daily expenditure of energy by the subjects were described in our preceding work.*

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*KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA, 1986, No 5.

Hormone concentrations were determined by radioimmunological methods using the kits of Sea Sorin, France (for cortisol, aldosterone and testosterone) and Wus-Malinckrodt, FRG (for T3 and T4) on types 1210 and 1270 LKB beta and gamma counters, Sweden. As a control we used NMS-I and NMS-II (United States).

Blood sugar concentration was measured by the neocuproine method; potassium and sodium, by flame photometry and chlorides, using mercury thiocyanate on flow-type automatic analyzers. Data from the automatic instruments and end results of analysis were processed on a computer according to structure and operating technology of the automated complex for biochemical blood panels [5, 6].

Commercial control sera from Technicon (United States) were used to check the quality of biochemical blood tests throughout the period of the study.

Data were submitted to mathematical processing by the method of variation statistics using the t criterion of Student. To assess correlation between blood biochemical parameters, we calculated the coefficient of correlation (r), reliability of which was determined on the basis of tabulated data [2] for a small number of cases.

Results and Discussion

Table 1 lists biochemical parameters of blood of essentially healthy men referable to 3 age groups before the study. We found reliable differences in levels of aldosterone, testosterone, T3, sugar, potassium, sodium and chlorides.

Dynamics of blood cortisol concentrations fluctuated in all groups (Table 2). Hormone level rose by the end of the 1st period of hypodynamia; it dropped reliably in the 2d period and rose again in the 3d. Maximum concentration of the hormone was noted in the 1st period—460.92±22.08 nmol/ℓ (group A) and minimum, in the 2d—244.54±16.01 nmol/ℓ (subgroup C_2).

Aldosterone dropped from 0.38±0.02 to 0.27±0.02 nmol/ℓ in the middle age group toward the end of the 1st period of hypodynamia, then rose in the 2d period and dropped again to 0.26±0.02 nmol/ℓ in the 3d. Analogous dynamics were observed in the 1st-3d periods for the A group. Unlike group B, in subgroups C_1 and C_2, aldosterone rose to 0.36-0.37 nmol/ℓ by the 7th-8th day in the closed environment, and stabilized at this level (subgroup C_1) or rose somewhat in the 2d period (subgroup C_2), after which it dropped to baseline values—0.23-0.26 nmol/ℓ.

Blood testosterone concentration changed similarly in all age groups: it decreased toward the end of the 1st period and increased in the 2d. After the rise there was a decline to values that were reliably lower than baseline levels in the middle group, 19.50±0.90 and 25.20±0.90 nmol/ℓ, respectively (P<0.01). In the older age group, there were no differences between testosterone levels in the 3d and 0 periods.

T3 concentration decreased reliably in group B (P<0.01) as compared to the 0 period and stabilized at the same level, 2.65-2.66 nmol/ℓ, in the 2d and 3d periods. In group A, hormone level continued to decline up to the 3d period. In subgroups C_1 and C_2, the decline effect was observed after an increase in concentration in the 1st period. In subgroup C_2, which exercised, the concentration of hormones reverted to baseline values in the 3d period, in contrast to the C_1 group.

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Table 1. Concentrations of hormones, sugar and electrolytes in blood serum of essentially healthy men before the study

Biochemical parameter	Group of subjects	$\bar{x} \pm S$	$\bar{x} \pm 2S$
Cortisol, nmol/ℓ	A	--	
	B	361,56±84,46	192,65—530,47
	C	380,05±92,46	195,13—564,97
Aldosterone, nmol/ℓ	A	—	
	B	0,38±0,10	0,18—0,58
	C	0,28±0,09	0,09—0,27
		$P_{B-C} < 0,001$	
Testosterone, nmol/ℓ	A	—	—
	B	25,20±4,59	16,02—34,38
	C	18,33±4,71	8,91—27,75
		$P_{B-C} < 0,001$	
T3, nmol/ℓ	A	--	—
	B	3,34±0,51	2,32—4,36
	C	2,73±0,44	1,85—3,61
		$P_{B-C} < 0,001$	
T4, nmol/ℓ	A	--	--
	B	124,80±19,89	85,02—164,58
	C	130,13±21,97	86,19—174,02
Sugar, mmol/ℓ	A	4,36±0,32	3,72—5,00
	B	4,64±0,51	3,62—5,66
	C	4,90±0,49	2,92—5,88
		$P_{A-B} < 0,05$	
		$P_{A-B} < 0,001$	
Potassium, mmol/ℓ	A	4,42±0,32	3,78—5,06
	B	4,64±0,41	3,82—5,46
	C	4,66±0,38	3,90—5,42
		$P_{A-C} < 0,05$	
Sodium, mmol/ℓ	A	144,52±3,20	138,12—150,92
	B	137,80±2,55	132,70—142,90
	C	140,40±2,19	136,02—144,78
		$P_{A-B} < 0,001$	
		$P_{A-C} < 0,001$	
		$P_{B-C} < 0,001$	
Chlorides, mmol/ℓ	A	106,08±2,64	100,80—111,36
	B	101,86±2,24	97,38—106,34
	C	101,73±1,97	97,79—105,67
		$P_{A-B} < 0,001$	
		$P_{A-C} < 0,001$	

As compared to T3, T4 level was less variable in all groups. In the B group, T4 concentration increased by the end of the 1st period, then decreased to 115.70±3.90 nmol/ℓ in the 3d period. In older patients, after a decrease in concentration of this hormone in the 1st and, particularly, the 2d period, there was an increase in the 3d period when its concentration was close to 0-period values.

Blood sugar decreased in all groups of subjects to 4.11-4.19 mmol/ℓ by the end of the 1st period, then increased to 4.30-4.44 mmol/ℓ in the 2d period and decreased again to 4.00-4.20 mmol/ℓ in the 3d period. In subgroups C_1 and C_2, the concentration of sugar became stabilized at the same level, 4.06-4.12 mmol/ℓ in the 1st and 2d periods, after which it rose to 4.33-4.67 mmol/ℓ in the 3d period.

Table 2. Dynamics of biochemical parameters of blood in essentially healthy men submitted to hypodynamia in a closed environment (0-3d periods), $\overline{X}\pm m$

Group	Period	Cortisol	Aldoster.	Testoster.	T3	T4	Sugar	Potassium	Sodium	Chlorides
A	0	—	—	—	—	—	4,36±0,08	4,42±0,08	144,52±0,80	106,08±0,66
	1	460,92±22,08	0,28±0,02	24,00±1,20	3,55±0,17	122,20±6,50	4,19±0,09	4,31±0,07	143,83±1,10	105,39±0,74
	2	342,24±16,56	0,50±0,04	24,60±0,90	3,03±0,17	113,10±6,50	4,30±0,06	4,09±0,14	138,78±0,27	101,66±0,53
	3	353,28±11,04	0,36±0,02	19,50±1,20	2,79±0,15	130,00±6,50	4,00±0,09	4,50±0,07	138,68±0,41	99,38±0,53
	P	$P_{1-2}<0,001$ $P_{1-3}<0,001$	$P_{1-2}<0,01$ $P_{1-3}<0,05$ $P_{2-3}<0,01$	$P_{1-3}<0,05$ $P_{2-3}<0,01$	$P_{1-2}<0,05$ $P_{1-3}<0,01$		$P_{0-3}<0,01$ $P_{2-3}<0,05$	$P_{2-3}<0,05$	$P_{0-2}<0,001$ $P_{0-3}<0,001$ $P_{1-2}<0,001$ $P_{1-3}<0,001$	$P_{0-2}<0,001$ $P_{0-3}<0,001$ $P_{1-2}<0,001$ $P_{1-3}<0,001$ $P_{2-3}<0,01$
B	0	361,56±16,56	0,38±0,02	25,20±0,90	3,34±0,10	124,80±3,90	4,64±0,10	4,80±0,08	137,80±0,50	101,86±0,44
	1	386,40±24,84	0,27±0,02	19,20±1,20	2,74±0,10	135,20±5,20	4,14±0,07	4,69±0,09	137,97±0,47	101,26±0,29
	2	298,08±13,80	0,34±0,02	23,70±0,90	2,65±0,10	133,90±5,20	4,44±0,12	4,51±0,09	143,15±0,54	103,69±0,52
	3	314,64±13,80	0,26±0,02	19,50±0,90	2,66±0,08	115,70±3,90	4,20±0,06	4,13±0,05	140,55±0,47	101,49±0,74
	P	$P_{0-2}<0,01$ $P_{0-3}<0,01$ $P_{1-2}<0,01$ $P_{1-3}<0,01$	$P_{0-1}<0,01$ $P_{0-3}<0,01$ $P_{1-2}<0,01$ $P_{2-3}<0,01$	$P_{0-1}<0,01$ $P_{0-3}<0,01$ $P_{1-2}<0,01$ $P_{2-3}<0,01$	$P_{0-1}<0,01$ $P_{0-2}<0,01$ $P_{0-3}<0,01$	$P_{1-3}<0,01$ $P_{2-3}<0,01$	$P_{0-1}<0,01$ $P_{0-3}<0,01$ $P_{1-2}<0,05$ $P_{2-3}<0,05$	$P_{0-2}<0,05$ $P_{0-3}<0,01$ $P_{1-3}<0,01$ $P_{2-3}<0,01$	$P_{0-2}<0,01$ $P_{0-3}<0,01$ $P_{1-2}<0,01$ $P_{2-3}<0,01$	$P_{0-2}<0,01$ $P_{1-3}<0,01$ $P_{2-3}<0,01$
C_1	0	378,67±31,74	0,23±0,03	19,23±1,74	2,02±0,08	131,82±7,93	4,85±0,11	4,67±0,09	140,47±0,61	101,10±0,49
	1	381,98±25,12	0,37±0,02	15,60±1,32	2,31±0,11	113,23±6,63	4,12±0,09	4,78±0,12	137,47±1,02	103,02±0,88
	2	377,57±25,59	0,35±0,02	19,20±1,86	2,20±0,09	114,01±7,67	4,06±0,05	3,91±0,08	138,55±1,01	102,20±0,33
	3	355,49±41,12	0,24±0,03	17,40±1,95	1,83±0,13	131,17±8,84	4,67±0,12	4,42±0,11	139,36±0,66	101,68±0,60
	P		$P_{0-2}<0,001$ $P_{0-3}<0,001$ $P_{1-3}<0,001$ $P_{2-3}<0,001$		$P_{0-1}<0,05$ $P_{1-3}<0,05$ $P_{2-3}<0,05$		$P_{0-1}<0,001$ $P_{0-2}<0,001$ $P_{1-3}<0,01$ $P_{2-3}<0,001$	$P_{0-2}<0,001$ $P_{1-2}<0,001$ $P_{2-3}<0,01$	$P_{0-1}<0,05$	$P_{1-3}<0,05$
C_2	0	354,94±23,46	0,26±0,03	18,60±1,35	1,95±0,13	125,32±6,63	4,91±0,23	4,80±0,16	140,64±0,68	102,12±0,19
	1	482,45±24,56	0,36±0,05	15,33±1,47	2,41±0,11	127,14±7,67	4,11±0,10	4,87±0,10	142,59±0,90	102,44±0,54
	2	244,54±16,01	0,40±0,05	22,02±1,35	2,36±0,10	119,34±7,41	4,11±0,16	—	—	—
	3	355,49±41,12	0,24±0,05	18,03±1,53	1,91±0,11	133,38±7,41	4,33±0,15	4,50±0,06	140,86±0,72	102,63±0,18
	P	$P_{0-1}<0,001$ $P_{0-2}<0,01$ $P_{1-2}<0,001$ $P_{2-3}<0,01$	$P_{0-2}<0,05$	$P_{1-2}<0,01$	$P_{0-1}<0,05$ $P_{0-2}<0,05$ $P_{1-3}<0,01$ $P_{2-3}<0,01$		$P_{0-1}<0,01$ $P_{0-2}<0,01$ $P_{2-3}<0,05$	$P_{1-3}<0,01$		

Potassium level dropped reliably (P<0.01-0.05) from 4.42 to 4.09 mmol/ℓ in
group A subjects in the 2d period, and from 4.80 to 4.13 mmol/ℓ in group B in the
3d period; it dropped from 4.67 to 3.9 mmol/ℓ in the 2d period in subgroup C_1,
and from 4.80 to 4.50 in the 3d period in subgroup C_2. After decline in the 2d
period, there was elevation of potassium level to 4.42-4.5 mmol/ℓ in group A and
C_1 subjects.

Blood sodium concentration dropped reliably (P<0.001) in group A subjects as their
stay in the closed environment increased, from 144.52±0.80 to 138.68±0.41 mmol/ℓ
in the 3d period. In the middle age group, Na concentration increased to 143.15±
0.54 mmol/ℓ in the 2d period then decreased to 140.55±0.47 mmol/ℓ. In the older
age group C_1, the differences in sodium concentration were reliable only between
0 and 1st periods (P<0.05). The change in sodium levels in group C_2 subjects
were unreliable. Dynamic parameters of chloride concentrations in A and B
group subjects were similar to those of sodium. In subgroup C_1, chloride content
increased somewhat by the 2d period, then decreased. In subgroup C_2, chloride
levels were rather stable throughout the test period.

Table 3. Coefficients of correlation between biochemical parameters of blood
in essentially healthy men submitted to hypodynamia

Biochemical parameters	Groups of subjects			
	A	B	C	
			C_1	C_2
Cortisol and aldosterone	—0,83*	—0,05	0,57	– 0,18
Cortisol and T3	—0,47	0,46	0,87*	0,13
Aldosterone and testosterone	0,26	0,99*	—0,42	0,29
T3 and T4	—0,27	—0,13	—0,90*	–0,60
Cortisol and sugar	0,07	—0,12	—0,44	—0,04
T3 and sugar	0,45	0,77*	—0,81*	—0,74*
Aldosterone and potassium	—0,66	0,63	—0,21	0,65
Aldosterone and sodium	—0,77*	—0,01	—0,92*	0,99*
Aldosterone and chlorides	—0,48	0,50	0,97*	0,15
Testosterone and sugar	0,97*	0,99*	0,33	–0,002
Testosterone and potassium	—0,40	0,52	—0,57	–0,66
Testosterone and sodium	0,42	0,11	0,71	–1,00*
Testosterone and chlorides	0,72*	0,58	–0,58	0,56
Potassium and sodium	0,24	—0,54	0,03	0,56
Sodium and chlorides	0,96.	0,82*	–0,93*	0,25

*Values for coefficient of correlation are reliable.

Analysis of correlation between hormones and other biochemical parameters of
blood (Table 3) revealed the following. In three age groups (A, B and C_1), r
between the same parameters had both positive and negative values. For example,
the markedly negative correlation between cortisol and aldosterone ($r = -0.83$;
group A) changed to a moderately positive one ($r = 0.57$; subgroup C_1); in
group B the relationship was mildly negative ($r = -0.05$). An analogous trend
was demonstrated between parameters of cortisol and T3 concentration. Group
B was an exception, and for it there was a moderate close correlation ($r = 0.46$).
The difference in direction of correlation was also noted between other para-
meters: aldosterone and testosterone, cortisol and sugar, T3 and sugar, aldo-
sterone and potassium, aldosterone and chlorides, testosterone and sugar, testo-
sterone and potassium, testosterone and chlorides, potassium and sodium, sodium

and chlorides. In some cases there was either only a negative correlation (between T3 and T4, ranging from -0.13 for group B to -0.90 for subgroup C_1, between aldosterone and sodium, r ranging from -0.01 for group B to -0.92 for subgroup C_1), or only a positive one (between testosterone and sugar, r from 0.33 in group C_1 to 0.99 in group B; between testosterone and sodium, r from 0.11 in group B to 0.71 in subgroup C_1). As compared to the control (subgroup C_1), exercises performed by subjects in subgroup C_2 altered appreciably the value of r in the direction of decline of other a positive correlation (between cortisol and aldosterone, cortisol and T3, aldosterone and chlorides, testosterone and sodium) or mild correlation (between aldosterone and potassium, aldosterone and sodium, sodium and chlorides, testosterone and chlorides). In two cases, there was virtually no change in values for r between T3 and sugar, testosterone and potassium.

The concentrations of biochemical constituents of blood of essentially healthy men prior to restriction of motor activity can be considered the norm. The reliable differences for aldosterone, testosterone, T3, sugar and potassium (see Table 1) as a function of age agree well with the data of other authors. As a rule, the levels of these hormones were lower in elderly people than in the young, while glucose and potassium levels rose [1, 15, 17]. The almost 1.5-2-fold decline of T3 in subjects over 50 years of age was associated with elevation of T4. The reverse is observed at the age of 20-50 years [9, 11]. We demonstrated an analogous tendency.

The complex dynamics of hormones during a long-term stay in a closed environment can be attributed to specific adaptation of the body to both hypokinesia and the different environment. Each stage of the hormonal effect--intake of original material by the cell for hormone synthesis, its synthesis by the gland and rate of secretion into blood, transport and complex formation with proteins in the vascular system, metabolism in the liver and inactivation, rate of excretion, sensitivity of organs (target tissues of hormonal action)--could have a substantial influence on blood hormone level and, consequently, elicit some metabolic effect. According to data in [12, 13], increase in blood concentrations of cortisol, testosterone and certain other hormones was associated with an increase in rate of their uptake by tissues. Hypokinesia diminished corticosteroid secretion by the adrenals and testosterone secretion by reproductive glands [3, 8]. We believe that this could be one of the causes of the most intensive decline of cortisol and testosterone levels in the 1st-2d periods of confinement. At the same time, the decrease in testosterone content could intensity catabolic processes in skeletal muscles.

It is known that cortisol inhibits tissular glucose uptake. The mechanism of development of hyperglycemia elicited by the hormone is attributable, in addition to gluconeogenesis, to decreased synthesis of glycogen in muscles and diminished oxidation of glucose in tissues. However, in a closed environment (see Tables 2 and 3), the progressive decline of sugar level, particularly for the first 15 days under hypodynamic conditions, was not always associated with a synchronous decline of cortisol. In this regard, it should be noted that T3 could also have affected blood glucose level. When the thyroid is hypofunctional, there is an increase in concentration of sugar. In our case, in 0-3d periods, when there were reliably low concentrations of T3 (1.83-2.02 nmol/ℓ), sugar level was highest (4.67-4.80 mmol/ℓ) in the older age group, with a

markedly negative correlation. We were impressed by the strong positive correlation between testosterone and sugar in group A and B subjects. In addition to the above-mentioned hormones, insulin, glucagon and catecholamines which, as we know, affect carbohydrate metabolism could have influenced the blood glucose level.

Another adrenal hormone, aldosterone, is instrumental in retention of sodium and chloride ions and, on the contrary, excretion in urine of potassium ions through reverse absorption of the first two ions by renal tubules [1, 16]. During the stay in a closed environment, the dynamics of aldosterone were reliable in subjects of all subgroups. However, there was no negative correlation between concentrations of hormones, sodium and chlorides. The latter circumstance could also be due to the influence of testosterone which, like aldosterone, affects reabsorption of sodium and chlorides by renal tubules. According to the data in [4], impairment of electrolyte balance, in particular hypokalemia, during hypokinesia could lead to functional change in the myocardium, which is reflected on the electrocardiogram.

Separate assays of T3 and T4 are the most informative in assessing the functional state of the thyroid. About one-half to two-thirds of the T3 circulating in blood is formed by deiodination of T4 on the periphery, and the rest is produced directly by the thyroid [1, 14]. T3 is about 4 times more active in affecting basal metabolism than T4. In our study, the most marked decline of T3 and prevalence of T4 were manifested in the 2d and 3d periods of confinement. According to data in [10], such changes in T3/T4 correlation may be specific manifestations of adaptation, with which there is limitation of catabolic processes and decline of basal metabolism.

As shown by the results of our investigation, during 1-month adaptation to hypokinesia in a closed environment, none of the biochemical parameters demonstrated stabilization. It is only in subgroup C_2 subjects, who performed a set of exercises, that the biochemical parameters of blood (cortisol, aldosterone, testosterone, T3, sodium, chlorides and, to a lesser extent, T4, sugar and potassium) reverted to baseline values. According to [7], the interval between 30 and 60 days corresponds to the 3d period of adaptation to hypokinesia, and it is characterized by stabilization of most functional parameters (pulse rate, reaction to orthostatic test, etc.). At the same time, both the 1st and 2d periods in our study corresponded to the stage of immediate adaptation (first stage lasting up to 7-10 days), according to the same criteria [7], when the subjects presented prevalence of a set of various forms of orienting responses, followed by the second stage (after 10 days) characterized by development of new stereotypes.

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EFFECT OF WEIGHTLESSNESS AND HYPOKINESIA ON VELOCITY AND STRENGTH PROPERTIES
OF HUMAN MUSCLES

[Article by L. S. Grigoryeva and I. B. Kozlovskaya]

[English abstract from source] Before and after exposure to
short- and long-term microgravity and prolonged bed rest velo-
city and strength parameters of leg muscles were measured by
isokinetic dynamometry. It was found that long-term exposure
to microgravity produced a more distinct decline of muscle
strength than short-term exposure. At the same time prolonged
bed rest led to greater strength losses than microgravity of
comparable duration. After long-term flights individual varia-
bility of changes was twice as high as after prolonged bed rest.
A comparable analysis of the above exposures demonstrated that
the changes observed after long-duration exposures were associ-
ated with atrophic changes due to disuse while those seen after
short-term effects were induced, as shown previously, by reflex
tonic shifts related to support unloading.

[Text] Changes on different levels of the motor system, which are manifested
by decline of its functional capacities, are among the adverse effects of
weightlessness [1-8]. One of the main elements in these changes, that can
be reduced to the general signs of the hypogravity motor syndrome [8], is
the change in properties of muscles. In preceding studies, a comparative ana-
lysis was made of the effect of short-term weightlessness and conditions that
simulate it on velocity and strength properties of muscles [3, 4, 6], which
enabled us to demonstrate the similarity of effects elicited by weightlessness
and immersion hypokinesia of equal duration, as well as the leading role of
reflex tonic mechanisms in the decline of contractile capacities of antigra-
vity muscles in the absence of static load.

This study is a continuation of the above investigations, and it deals with
the velocity and strength properties of muscles under the long-term effect
of weightlessness and conditions that simulate it, as well as comparative ana-
lysis of the effects of long-term and short-term exposure.

Methods

We tested the velocity and strength properties of crural antagonist muscles--
anterior tibial muscle (ATM) and sural triceps (ST) by the method of isokinetic
dynamometry at angular accelerations of ankle movement of 180, 120, 60 and 0°/s.
The tests were performed with an isokinetic dynamometer, with recording of
developed moments of force and goniograms of movements. The technique for iso-
kinetic testing was described in greater detail in previous works [4, 6].

We conducted this study on 14 subjects before and after 120-day bedrest hypo-
kinesia in antiorthostatic position [head-down tilt], on 6 main mission crew
members before and after spaceflights aboard the Salyut-7 station lasting 110
to 237 days, and on 12 crew members involved in rendez-vous mission lasting
7 days.

Results and Discussion

The results of our study revealed that long-term spaceflight, like bedrest,
leads to statistically reliable (P<0.01) decline of strength characteristics of
the tested sural muscles over the entire range of velocities including static
(0°/s) and dynamic modes of low (60°/s), moderate (120°/s) and high (180°/s)
velocities of motion in the ankle joint. A comparison of the demonstrated
changes to distinctions of effects of short-term spaceflights (Figure 1) estab-
lished that the substantial distinction of long-term exposure to weightlessness
is the decline of strength properties not only of the ST, but ATM over the
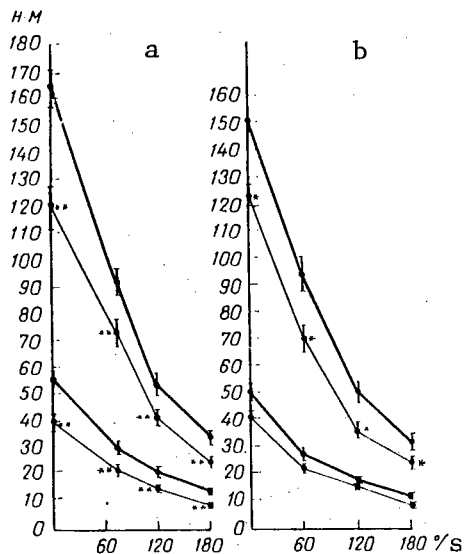entire range of velocities.

Figure 1.
Velocity and strength properties of sural
muscles before and after exposure to
weightlessness for different periods of
time
 X-axis, angular velocity of motion (in
 degrees per second); y-axis, developed
 moments of force (in H•m)
a, b) long- and short-term weightlessness,
      respectively
Top pairs of curves--ST parameters, bottom--
ATM. Statistically significant differences
with P<0.05 and P<0.01 are indicated by one
and two asterisks, respectively. Mean
values, M±m, are given

On the other hand, we were impressed by the fact that the decline of strength
parameters of ST were rather similar after long-term and short-term missions
at the same velocities of all dynamic modes, as can be seen in Figure 1, and it
is only in the isometric mode that they were somewhat higher after long-term

flights. Such a comparison of the results of effects of flights differing significantly in duration indicates that the physical preventive measures used by crews of long-term missions had a substantial attenuating effect.
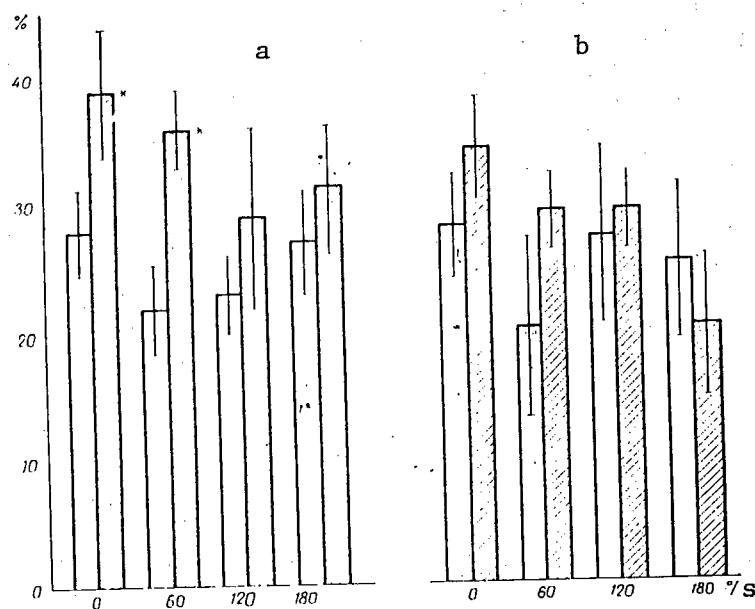

Figure 2. Mean levels of decline of strength parameters of calf muscles at different velocities of motion following long-term exposure to weightlessness and hypokinsia. X-axis, angular acceleration of motion (°/s); y-axis, decline (%)

a) ST parameters   b) ATM parameters

White bars show weightlessness conditions and striped, hypokinesia; vertical segments indicate standard error. The asterisk indicates statistically reliable differences (P<0.05)

This is also indicated by the results of comparing the effects of long-term weightlessness and conditions simulating it without the use of preventive measures. Figure 2 illustrates mean levels of decline of strength parameters of ST and ATM at different velocities of motion following long-term flights and 120-day hypokinesia. As we see, after hypokinesia the greatest loss of strength was demonstrated in the ST in isometric and low-speed modes, and it constituted a mean of 40%; at higher velocities, the loss did not exceed a mean of 30%. In the ATM, the decline of strength parameters following hypokinesia was relatively less marked and constituted about 35% in isometric mode, 30% at low and moderate velocities and about 20% at high speed. Thus, we found the same trend toward more marked changes in strength modes and less marked in velocity modes with respect to the decline in velocity and strength properties of the sural extensor and flexor following hypokinesia.

As can be seen in Figure 2, the decline of strength parameters of calf muscles was less marked after long-term flights than hypokinesia, and it ranged from 20 to 28% at different speeds. And (unlike hypokinetic conditions), we failed

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to demonstrate a tendency toward more marked decline in the strength modes. On the contrary, as can be seen in Figure 2, relatively greater loss was noted in both tested sural muscles in the alternative modes--isometric and high-speed.

Comparative analysis revealed that differences in extent of decline of strength following weightlessness and hypokinesia were the most marked and statistically reliable (P<0.05) in the ST in isometric and low-speed (strength) modes. This difference can apparently be attributed to use of physical preventive means by crews of the main missions.

The difference in distribution of strength loss as a function of testing speed could be related to the distinctions of motor activity in weightlessness and under hypokinetic conditions. The deeper changes in strength modes following hypokinesia is attributable to the fact that expressly these modes of muscular activity are virtually precluded by the hypokinetic conditions. In weightlessness, when operators did not use physical preventive measures, not only load-related strength modes of muscular activity, but (due to inertia) rapid movements are precluded. This apparently explains the predominant changes in strength modes following hypokinesia, and in strength and high-speed modes following long-term flights.

The above-indicated differences in nature and severity of demonstrated changes following long- and short-term flights are apparently attributable to a difference in mechanisms of their development. As we have already mentioned, prior studies dealing with the distinctions and mechanisms of effects of short-term weightlessness and hypokinesia demonstrated the leading role of the mechanism of diminishing muscle tone, which occurs in response to removal of static load with decrease in contractility of antigravity muscles. A consistent effect, in the form of 20-30% decline in strength parameters over the entire range of velocities (in both weightlessness and with immersion hypokinesia lasting 7 days), was demonstrable primarily in extensors more closely related to tonic innervation, as confirmed by direct testing of transverse strength of muscles [3, 6]. The decline of velocity and strength properties following long-term exposure to weightlessness and hypokinesia is apparently related to addition of atrophic processes in muscle tissue to the tonic changes. The recovery time from the demonstrated changes, which constituted about 1.5-2 months in most subjects, is also indicative of the atrophic nature of decline in muscle contractility under the above conditions. It should be stressed that, in addition to the above-mentioned distinctions, the demonstrated decline in parameters not only of extensors but flexors of the calf is a substantial argument in favor of the atrophic nature of changes following long-term weightlessness and hypokinesia.

Analysis of individual extent of changes revealed that maximum decline of strength parameters in the tested range of velocities fluctuated between 20 and 50% in different subjects following long-term flights (mean being 20-30%), and between 30 and 60% (mean about 40%) following 120-day hypokinesia. There was a correlation between individual degree of changes and duration of the recovery period. At the same time, we failed to demonstrate a reliable correlation between baseline individual strength properties and extent of strength loss. It should be noted that individual variability of changes, as assessed by the coefficient of variation, was 2 times greater following long-term flights than after hypokinesia (40-60% versus 20-30%).

Thus, this investigation enabled us to demonstrate that long-term weightlessness and hypokinesia elicit a decline of muscle strength in different velocity modes, and considerably more after hypokinesia, and this is apparently indicative of the efficacy of physical means of prevention used by the crew of the main mission.

Individual severity of these changes varies appreciably following long-term flights and, in the absence of reliable correlation between baseline strength properties and severity of demonstrated changes, this is apparently a reflection of the individual level of performance of preventive measures.

The nature of decline of muscle strength during long-term absence of a static load is, unlike short-term exposure, related to atrophic processes which develop consistently as a result of the known "disuse" effect.

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PROBABILITY OF ALTITUDE DECOMPRESSION DISORDERS AS A FUNCTION OF DURATION OF PRE-EXPOSURE TO HYPOBARIC ATMOSPHERE

[Article by V. I. Chadov, A. S. Tsivilashvili, and L. R. Iseyev]

[English abstract from source] Healthy volunteers, aged 21-47 years, were kept in an altitude chamber. Before decompression to a residual pressure of 293.3 GPa the test subjects were consecutively exposed to 1120 GPa for 2 h and then to 733.3 GPa for 24, 18 or 12 h. At 293.3 GPa the test subjects performed a moderate workload for 6 h. It has been concluded that prior to the use of a space suit with the working pressure 0.3 kgf/cm^2 (293.3 GPa) the time of exposure to a hypobaric normoxic (29-30% O_2) atmosphere with the total barometric pressure 733.3 GPa should not be less than 18 h and it should preferably be 24 h. In this situation decompression safety of 6 h extravehicular activity can be predicted with a high probability.

[Text] It is known that barometric pressure of up to about 400 hPa [translator's note: Although source's English summary uses GPa, Russian lower case gPa in text refers to hecto, i.e., hPa] is relatively safe with respect to onset of altitude decompression disorders (ADD). This circumstance served as the basis for selecting working pressure in Soviet space suits of 0.4-0.42 kgf/cm^2 (392-411 hPa) [1, 12]. Yet, mobility in the suit is appreicably restricted at such working pressure and consequently it is difficult for man to work in it. To improve flexibility of the space suit it is necessary to lower significantly the working pressure under its casing. However, any drop of pressure would increase the probability of ADD when engaged in extravehicular activity [EVA]. Brief desaturation presently used to prevent them would not be very effective when using space suits with low working pressure.

This problem can be solved by lowering pressure in the spacecraft cabin, i.e., producing an artificial hypobaric atmosphere with normalized partial oxygen pressure. The idea of using a hypobaric environment in spacecraft as a means of preventing development of decompression disorders during EVA in a space suit with low pressure is far from being new. The guidelines for producing such an environment and validating its main parameters have been discussed in a number of Soviet and foreign sources [2-10, 13, 15, 18]. P. M. Gramenitskiy,

on the basis of his own special investigations and comprehensive analysis of the question as a whole [9], arrived at the general conclusion that "... a two-component nitrogen and oxygen gas atmosphere with moderately lowered total pressure and normalized partial oxygen pressure is a promising preventive means against decompression disorders during spaceflights." It should be noted that this guideline for preventing ADD was implemented in the Soyuz-Apollo project in 1975, in providing for the safety of crews' movements from one spacecraft to the other [4, 5].

In a hypobaric normoxic environment, partial nitrogen pressure is lower than usual, and exposure to it leads to gradual decline of initial nitrogen tension in body tissues. If one starts to lower cabin pressure and form a new atmosphere during insertion of the craft in orbit and it is discontinued within the first few minutes of orbital flight, partial desaturation from nitrogen and dynamic equilibrium of gases with the environment will become established at a new, lower level after the first few days of flight [10, 16, 19] or, according to some data, somewhat sooner [7, 17] or later [11, 14]. From this time on, it is desirable and, mainly, possible to use a lower working pressure in the space suit for all the remaining phases of the mission, the minimum allowable level of which will be determined by the partial nitrogen pressure in the cabin atmosphere and corresponding coefficient of allowable oversaturation.

The problem is somewhat more complicated if the air atmosphere in the spacecraft is at a somewhat higher than atmospheric pressure before lift-off. The period of prelaunch anticipation could be rather long, and during this time there would be additional saturation of the body with nitrogen. In this case, initial saturation of different tissues with nitrogen by the time of an EVA, which also means the minimum safe working pressure in the space suit, with regard to decompression risk, will depend on partial nitrogen pressure in the cabin atmosphere in the prelaunch period, duration of this presaturation period, parameters of subsequent hypobaric environment and time spent in it (desaturation).

Our objective here was to explore the possibility of onset of ADD at a residual pressure of 293.3 hPa as a function of duration of prior exposure to hypobaric normoxic atmosphere with total pressure of 733.3 hPa following 2-h exposure to an air environment at a pressure of 1120 hPa.

Methods

The studies were conducted in an altitude chamber 110 m^3 in size, with the participation of volunteers 21-47 years of age. Three to six people participated in each test. We conducted three series of tests. Each one involved two preliminary and one main stage. The first preliminary stage simulated possible conditions in the cabin of a spacecraft directly prior to lift-off and involved a 2-h stay in an air environment with total pressure of 1120 hPA (840 mm Hg, 1.14 kgf/cm^2) at a temperature of 20-22°C and relative air humidity of 35-40%. The second preliminary stage simulated a stay in the cabin at low pressure and normalized partial oxygen pressure for 1 day of orbital flight. Normoxic hypobaric conditions were obtained by producing a rarefied atmosphere in the chamber at total pressure of 733.3 hPa (550 mm Hg, 0.75 kgf/cm^2, altitude of 2650 m) with concurrent increase to 29-30% oxygen. In the 1st series of tests, the hypobaric stage lasted 24 h, in the 2d series 18 h and in the 3d series 12 h. At the preliminary stages of the study, the subjects did not

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perform any special physical work. The main stage of the test simulated conditions of operator work outside the spacecraft in space suits at a working pressure of 0.3 kgf/cm^2 (293.3 hPa, 220 mm Hg, altitude 9300 m). At this stage, the subjects breathed a gas mixture consisting of 95-96% oxygen and 5-4% nitrogen. This stage lasted 6 h. During this time, the subjects periodically performed graded arm exercises, which consisted of moving a special double-armed lever at chest level just in front of them (forward and backward) at different tempos. Overall duration of work and rest periods constituted 40 and 20 min, respectively, per hour. Energy expended by the subjects ranged from 4 to 6 kcal/min, depending on the exercise pace. ADD was identified on the basis of subjective sensations and objective clinical symptoms. We conducted a total of 156-man-tests involving 43 subjects.

Results and Discussion

The general results of our tests are listed in the table.

Incidence of ADD in different series of tests

Test series	Test stage			Number of man-tests	Number of subj.	Number of ADD	Number of subjects with ADD
	I	II	III				
I	1120/2	733,3/24	293,3/6	69	37	None	None
II	1120/2	733,3/18	293,3/6	51	30	1	1
III	1120/2	733,3/12	293,3/6	36	27	6	6

Note: Barometric pressure (in hPa) is given in numerator and duration of stage (h), in the denominator.

The entire protocol of the test in the first series was completed. No signs of ADD were demonstrable in any subjects (most of them were tested twice). All of the subjects tolerated the test conditions well.

The obtained data enabled us to conclude that 24-h exposure to a normoxic hypobaric atmosphere at total pressure of 733.3 hPa following 2-h prior exposure to a hyperbaric air environment (1120 hPa) preventis development of ADD rather reliably in an individual performing moderate physical labor for 6 h, at residual pressure of 293.3 hPa.

The positive results of the 1st series of tests raised the question of whether the same effect could be obtained in the case of shorter exposure to a hypobaric environment. For this purpose, we conducted two more series of tests, in which exposure to the hypobaric atmosphere lasted for 18 h (2d series) and 12 h (3d series). According to data in the table, ADD occurred only in 1 out of 51 tests in the 2d series. The subject complained of pain in the wrist and elbow of the right hand in the 75th min of exposure to residual pressure of 293.3 hPa. The pain did not go away within 5 min of relative rest, and for this reason the test was stopped and the subject was brought "down." Pain began to diminish during compression and disappeared entirely at 472 hPa (altitude 6000 m). The subject presented no complains after his "descent." A physical examination

failed to demonstrate any deviations in his health status. The other 50 man-tests were completed with fulfillment of the entire program. None of the 29 subjects presented any complaints that could be indicative of ADD.

In the 3d series, in 6 out of 36 tests, 6 subjects developed ADD at different times, which were manifested by pain in different joints in 3 cases, and by pruritis, scratchy throat and cough, and general weakness each in 1 case.

The data indicate that performance of moderate physical work at residual pressure of 293.3 hPa following 2-h exposure to hyperbaric environment and 18-h in a normoxic hypobaric atmosphere could lead to development of relatively mild forms of ADD in some individuals. However, it must be noted that the subject who developed ADD was referable to people with hypersensitivity to decompression factors. He presented pain in muscles and joints often in other tests, including those with residual pressure of about 411-392 hPa.

Reducing exposure time of normoxic hypobaric conditions to 12 h leads to significant increase in probability of decompression disorders. In most cases, there were mild disorders, whereas in 2 cases ADD disappeared after a 5-min rest and did not return thereafter, so that the subjects could perform the entire program. Nevertheless, it should be noted that 12-h exposure to a normoxic hypobaric atmosphere after 2-h hyperbaric atmosphere did not prevent development of ADD in a sufficient number of cases when performing moderate work in a rarefied atmosphere at residual pressure of 293.3 hPa.

Thus, the results of these studies revealed that pre-exposure to hypobaric (733.3 hPa) normoxic (29-30% O_2) atmosphere in the cabin should last at least 18 h, or better yet 24 h, if it is planned to use a space suit with working pressure of 0.3 kgf/cm^2 for EVA. On this condition, there is a sufficient degree of reliability of assuring decompression safety of 6-h EVA. The need to use a space suit following briefer exposure to the above-mentioned hypobaric environment requires use of higher working pressure under the suit shell.

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SOME INDIVIDUAL DISTINCTIONS OF HUMAN ADAPTATION TO ALTITUDE

[Article by V. A. Berezovskiy, T. V. Serebrovskaya, and A. A. Ivashkevich]

[English abstract from source] Two groups of young healthy men—natives of lowlands who for one year lived and worked in chronic hypoxia (Group 1 at an altitude of 1680 m with P_{O_2} = 120 mm Hg and Group 2 at an altitude of 3650 with P_{O_2} = 90 mm Hg) were examined. It was found that after this prolonged exposure the subjects showed a higher sensitivity of the respiratory system to hypoxia, an enhanced lung ventilation and circulation, a lower gas exchange and physical work capacity. The concentration of lactic acid at rest in the Group 2 subjects was 47% higher than in the Group 1 subjects. The lactate/pyruvate ratio in the Group 2 subjects increased by 46% thus indicating an enhanced rate of anaerobic processes. A higher deficiency of buffer bases, a lower concentration of bicarbonates in blood at rest and during exercise tests of the Group 2 subjects pointed to metabolic acidosis. The subjects with a higher rate of anaerobic metabolism in a low P_{O_2} environment displayed a diminished sensitivity of the hypoxic stimulation of respiration, an increased tolerance to the very low P_{AO_2} and a reduced work capacity in chronic hypoxia.

[Text] The genetic polymorphism of biochemical traits in man offers wide opportunities for individual variations in reactivity, resistance to various extreme and close to extreme conditions, including hypoxia. Along with development of systemic reflex adaptive reactions in adaptation to hypoxia, there are also tissular adaptive processes [3, 4, 9]. Experiments on animals revealed that the adaptation process is associated with intensification of anaerobic glycolysis, with increase in blood concentration of lactic acid and in lactose/pyruvate ratio [11, 13]. The existing information about glycolytic processes in man under analogous conditions is rather contradictory, and it was obtained primarily when breathing hypoxic gas mixtures [6] or during brief (10-30 days) stays in the mountains [5, 15, 17].

Our objective here was to test the effect of a year-long exposure to chronic hypoxia on individual distinctions of glycolytic processes, and to detect a possible link between these processes and work capacity.

Methods

The studies were conducted on two groups of healthy young men indigenous to the lowlands. The 1st group consisted of 24 men (19.6±0.2 years of age, weight 64.3±1.5 kg, height 173±1.4 cm) who spent a year at p_iO_2 = 120 mm Hg; the 2d group consisted of 17 men (age 20.5±0.5 years; weight 69.6±1.7 kg; height 173±1.4 cm) who spent 1 year at p_iO_2 = 90 mm Hg. The 1st group was examined at p_iO_2 = 120 mm Hg and the 2d at p_iO_2 = 90 mm Hg. The tests were made in the morning on a fasting stomach. Parameters of external respiration and gas exchange were measured in supine position, at rest. Respiratory minute volume ($\dot{V}_E$) was recorded using a VEB MLW (GDR) volumeter, and exchange of gases was determined according to Douglas-Haldane. Gases were analyzed on GVV-2 and AKTs-16 instruments. Sensitivity to hypoxia was assessed by the rebreathing method with uptake of CO_2 on a Metatest spirograph without stabilization of p_ACO_2. Gas levels in alveolar air were monitored by cutting off and analyzing end portions of exhaled air using an electronic cut-off. Breathing in the spirograph lasted about 4 min. The procedure was stopped upon appearance of the first signs of disruption of verbal contact with the subject. The subjects were interested in determining their maximum altitude ceiling. The level of physical work capacity ($\dot{W}$) and maximum oxygen uptake ($\dot{V}_{O_2max}$) were assessed by the PWC_{170} test. Arterial pressure was drawn from a warmed finger at rest and within the first 15 s after a graded physical load (75% of nominal $\dot{V}_{O_2max}$). Blood pH was determined on an OP-212 (Radelkis, Hungary) analyzer. Parameters of acid-base equilibrium were calculated from nomograms of Siggaard-Andersen. Lactic acid (LA) concentration was determined using a previously published technique [14] and pyruvic acid (PA), according to data in [2]. Correlation and variance analysis was made using a bank of "Biological Medical Programs" run on an operational EC [computer] system.

Results and Discussion

The results of these studies revealed substantial differences in physiological and biochemical parameters between the 1st and 2d groups of subjects. Minute respiratory volume was increased in the 2d group ($\dot{V}_E$ – 165±8.1 ml/min/kg), as compared to the 1st group (153±5.7 ml/min/kg), mainly at the expense of tidal volume. This is associated with increased efficiency of breathing, as well as increased share of alveolar ventilation in the overall volume of pulmonary ventilation (72.1±1.38% in the 2d group and 68.8±1.45% in the 1st). Chronic hypoxia elicits an increase in sensitivity of the system of external respiration to the hypoxic stimulus: $\Delta\dot{V}_E/\Delta p_AO_2$ is 10.8±1.15 ml/min/kg/hPa in the 1st group and 23.4±3.4 ml/min/kg/hPa in the 2d. There is relative tachycardia, the heart rate at rest being 72±2.6 min^{-1} in the 2d group and 54±1.8 min^{-1} in the 1st. Systolic blood pressure was also somewhat elevated (119±1.6 mm Hg in the 2d group and 107±2.1 mm Hg in the 1st). O_2 uptake and CO_2 output were low in the 2d group of subjects: $\dot{V}_{O_2}$ was 3.9±0.1 ml/min/kg in the 2d group and 4.4±0.2 ml/min/kg in the 1st; $\dot{V}_{CO_2}$ constituted 3.1±0.1 and 3.7±0.2 ml/min/kg, respectively.

Lactic acid concentration at rest was 47% higher in the 2d group than in the 1st (see Table). There were no differences in pyruvic acid content. The 45% higher LA/PA ratio in the 2d group of subjects is indicative of intensification of anaerobic processes with p_iO_2 = 90 mm Hg. In addition, there was a more

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marked buffer base deficiency in the 2d group of subjects (BE = -10.5±0.71 mmol/ℓ) as compared to the 1st group (BE = -7.4±0.81 mmol/ℓ) and the decline of blood bicarbonates are indicative of development of metabolic acidosis. However, blood pH did not change, i.e., the acidosis was compensatory.

Some biochemical parameters of blood at rest and with graded physical load during 1-year exposure to hypoxia (M±m)

Group of subjects	LA		PA		LA/PA		pH		$\dot{W}_{170}$, kPm/min/kg*	$\dot{V}O_2$ max. ml/min/kg
	at rest	physical load	at rest	phys. load	at rest	phys. load	at rest	phys. load		
1	19,4 ±1,06	26,2 ±2,2	1,05 ±0,002	1,17 ±0,02	18,3 ±1,23	22,5 ±1,82	7,343 ±0,01	7,303 ±0,01	24,2 ±1,66	64,6 ±4,0
2	28,5 ±2,19	35,1 ±3,4	1,07 ±0,017	1,17 ±0,02	26,7 ±1,92	29,7 ±2,42	7,349 ±0,012	7,259 ±0,012	18,5 ±0,89	54,6 ±2,93
	<0,001	<0,05	>0,05	—	<0,001	<0,02	>0,1	<0,01	<0,01	<0,05

*Expansion of kPm unknown.

The tests with graded exercise revealed a decline of physical work capacity in the 2d group of subjects, as manifested by decline of $\dot{W}_{170}$ and $\dot{V}_{O_2max}$ parameters. With performance of the same work, blood LA level at $p_iO_2 = 90$ mm Hg as 34% higher than at $p_iO_2 = 120$ mm Hg, and LA/PA ratio was 32% higher (see Table). Performance of graded exercise was associated with a large shift of blood pH in the direction of acidity (BE constituted -12.4±0.54 mmol/ℓ in the 2d group and -6.6±0.92 mmol/ℓ in the 1st). The acidosis was decompensated.

Analysis of individual distinctions of biochemical adaptation to chronic hypoxia revealed that individuals characterized by high intensity of anaerobic metabolism at rest under hypoxic conditions differed from those with low LA/PA with respect to several functional values. To confirm this thesis, we performed correlation and variance analysis of the features studied in relation to LA/PA. All of the subjects were divided into three subgroups: one subgroup consisted of those in whome LA/PA was in the range of M±1σ on the curve of normal distribution of this parameter. Individuals whose LA/PA exceeded this range made up the other two subgroups. The data for these subgroups are illustrated in the figure.

Analysis of the findings revealed that individuals with intense glycolysis had a significantly lower sensitivity of respiration to the hypoxic stimulus. This was manifested by a less marked slope of the curve for the ventilation response of $\Delta\dot{V}_E/\Delta p_AO_2$ (see Figure, b; $r = -0.51$; P<0.01) and lower p_AO_2 levels (see Figure, c; $r = -0.52$; P<0.01) in these subjects. Their physical work capacity was also diminished (see Figure, d; $r = -56$; P<0.01). When performing graded exercise, these subjects presented a greater increment of LA/PA, greater decline of pH and greater shortage of blood buffer bases (see Figure, e, f).

The results of these studies revealed that man's exposure for 1 year to $p_iO_2 = 90$ mm Hg is associated with marked adaptive changes in the system of regulation

of respiration and gas exchange, changes in biochemical parameters of blood. There was an increase in sensitivity of the respiratory center to hyperoxia, development of hyperventilation and intensification of circulation. The adaptive reactions do not lead to complete compensation of chronic hypoxia, and there is development of signs of secondary tissular hypoxia, with decline of physical work capacity.
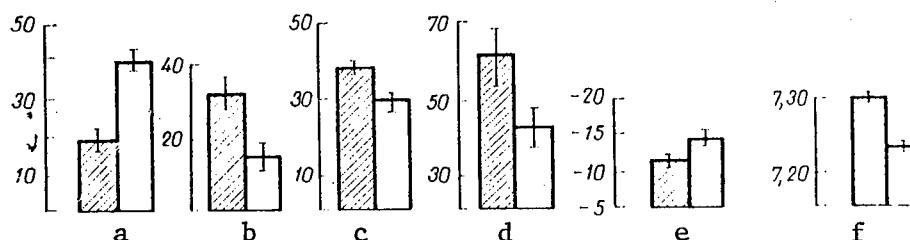
Some physiological and biochemical parameters of subjects with low (striped bars) and high (white bars) levels of anaerobic glycosis under conditions of chronic hypoxia (p_iO_2 = 90 mm Hg)

a) blood LA/PA ratio at rest (%)
b) ventilation response to hypoxic stimulus of respiration (ml/min/kg/hPa)
c) end p_AO_2 at moment of stopping test with increasing hypoxia (hPa)
d) maximum oxygen uptake during exercise (ml/min/kg)
e) shift of arterialized blood buffer bases during graded exericse (mmol/l)
f) pH of arterialized blood during graded exercise

It is a known fact that work capacity diminishes during long stays at high altitudes. According to M. M. Mirrakhimov [7, 8] and A. A. Aydaraliyev [1], main's stay for 2 years at an altitude of 3600 m and regular work do not provide the efficiency observed in the lowlands. There is information in the literature concerning diminished exchange of gases in the presence of chronic hypoxia [3, 8, 18 and others]. Authors relate this to diminished thyroid function and intensification of anaerobic processes, i.e., adaptation at the expense of diminished oxygen requirement.

It is believed that blood LA level is a rather reliable indicator of degree of hypoxia, and it can be used as a prognostic criterion [10, 16]. The obtained data referable to high level of LA with chronic hypoxia and its inverse relationship to physical work capacity confirm this point of view.

The results of these studies warrant the belief that healthy subjects of the same sex and age adapt differently to hypoxic hypoxia. Some develop strong compensatory reactions, significantly increased ventilation sensitivity to hypoxia, increased pulmonary ventilation and circulation, as a result of which there is insignificant elevation of blood LA Level, and physical work capacity is at a high level. However, the same individuals present low resistance to maximum pO_2 values, with increase in end pO_2 of alveolar air during rebreathing. At the same time, individuals characterized by a high level of anaerobic

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glycolysis, with high LA/PA ratio, diminished ventilation sensitivity to hypoxia and diminished physical work capacity turned out to be more resistant to maximum pO_2 in inhaled air. Previously, experiments on rats with high and low resistance to acute hypoxia revealed that a greater increase in anaerobic glycolysis during adaptation to hypoxia is observed in animals that are highly resistant to acute hypoxia [11, 12]. On this basis, the opinion has been voiced that intensification of glycolysis as a reserve mechanism renders tissues less sensitive to various deleterious factors. The results of human studies revealed that such a strategy of adaptation is instrumental in better tolerance to hypoxia; however, physical work capacity is diminished.

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ATROPINE TEST DISTINCTIONS IN INDIVIDUALS OF DIFFERENT AGE GROUPS

[Article by Kh. Kh. Yarullin and N. P. Artamonova]

[English abstract from source] The diagnostic value of the atropine test was investigated in 47 essentially healthy men of different age groups (25-39, 40-49 and 50-59 years). The cardiovascular responses were evaluated from ECG recorded continuously for an hour after subcutaneous injection of 1.0-0.1% atrophine sulphate. Atropine caused a two-stage effect of the cardiac chronotropic function. The first, bradycarditic, stage was induced by vagal stimulation while the second, tachycarditic, stage was, by contrast, produced by atropine blockade of the acetylcholine effect on M-cholino-receptors of myocardial cells. The atropine effect was identical in sign in all age groups. However, in the young age group the bradycarditic effect was more distinct and atropine-induced arrhythmias were more frequent. In the 50-59 years subjects the tachycarditic effect grew at a slower rate and the electric systole response to a higher heart rate was less pronounced.

[Text] A test involving hypodermic injection of atropine is not uncommon in cardiological practice for evaluation of cardiac function.

Atropine is an agent that has a direct effect on m-cholinoreceptors. The latter, as we know [1, 4, 9], are situated in the postsynaptic membrane of effector organ cells near the endings of postganglionic cholinergic (parasympathetic) fibers. They are also present in the cerebral cortex, reticular formation. By blocking m-cholinoreceptors, atropine renders them insensitive to acetyl-choline, which is formed in the terminal region of postganglionic parasympa-thetic nerves. For this reason, the effects of atropine are the opposite of the effects observed upon stimulation of parasympathetic nerves.

Our objective here was to determine the diagnostic value of the atropine test as related to individuals in different age groups.

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Methods

We performed the test involving hypodermic injection of 1.0 ml 0.1% atropine sulfate solution on 47 essentially healthy men of different ages. The 1st group consisted of 17 men 25-39 years old, the 2d of 25 people 40-49 years old and the 3d, 5 men 50-59 years old. Concurrently, we recorded the ECG in three standard leads (in some subjects we used three Nehb leads) on a Mingograph-82 with paper feeding at the rate of 50 mm/s. The ECG was recorded before giving atropine (in supine position, at rest, at maximum inspiration and expiration) and after it (every 3 min for the first half hour and every 5 min in the second half hour).

We determined duration of cardiac cycle RR (and, accordingly heart rate [HR] per min), PQ interval and electrical systole QT, as well as actual (a) and nominal (n) systolic index (SI) as a percentage, amplitude of P and T waves. The results of the tests were processed by the method of variation statistics after Student. Reliability of intragroup changes was determined by the sign criterion.

Results and Discussion

Analysis of HR revealed that administration of atrophine elicited a two-phase reaction in most healthy subjects. As also noted previously by other authors [3, 13], this effect was manifested first in the form of slowing then, after 25-30 min, acceleration of heart rate, i.e., a vagomimetic phase with slower sinus rhythm is followed by a vagolytic phase with faster sinus rhythm. By inhibiting central and perpheral effects of the vagus, atrophine can shift autonomic equilibrium in the direction of prevalence of adrenergic influences on the myocardium. As seen in Table 1, there was a tendency toward slower rate in all groups of subjects up to the 15th min after giving atropine, whereas in the 24th min, on the contrary, HR began to increase up to the 40th-60th min. HR increment virtually ceased by the 40th min in the 1st group, 50th min in the 2d, whereas in the 3d group of subjects it continued to the 60th min. Thus, there was slower increase in adrenergic effects on the heart and they lasted longer in the older age group. A sensation of mild driness of the mouth, which persisted to the end of the observation period, developed in most subjects of all groups (in 29 out of 47) starting in the 27th-30th min.

Table 1. Dynamics of mean values for heart rate (per min) in men of different age groups under the effect of atropine

| Subject group	Before atrop.	Time after atropine, min						
		9	15	24	30	40	50	60
1	62,8±3,55	60,7±3,76	60,0±4,59	63,8±3,96	66,8±4,03	73,0±4,61	73,9±6,12**	73,6±7,94*
2	68,2±1,97	64,6±1,29	60,9±1,09**	61,9±1,50	64,08±1,66	69,3±1,92*	73,2±1,92*	73,3±2,40*
3	65,8±3,21	65,4±4,50	64,7±4,07	67,2±2,79	70,0±4,29	74,0±6,00	75,8±7,72*	77,4±5,79*

Note: Here and in Table 2: *P<0.05   **P<0.01

Since atropine initially has an excitatory vagal effect then a block of cholinergic receptors, one can expect rhythm disturbances when it is given.

Before the atropine test, resting sinus rhythm was correct in 15 subjects of
the 1st group, 1 man presented a tendency toward tachycardia (HR 83-85/min) and
another demonstrated two monotpic ventricular extrasystoles at rest and in
maximum inspiration, which did not appear again during the test. Two subjects
showed migration of rhythm within the right atrium during maximum inspiration.
It occurred again during the atropine test before the 21st min in 1 case and
in the 21st-32d min of the test in the other. In two subjects, rhythm disorder
appeared first during the test proper, or more precisely in its first phase,
when activation of the vagus was demonstrable. Thus, one subject showed a
bottom left atrial rhythm from the 16th to 35th min of the test, whereas in
the other injection of atropine initiated appearance on the ECG of atrioventri-
cular dissociation followed briefly by an atrioventricular rhythm. This rhythm
disorder is illustrated in the figure. Subject V., 32 years old, is essentially
healthy. His resting ECG in the 3 leads of Nehb was normal; it also remained
normal at maximum inspiration (see Figure, a and b). In the 16th min, atrio-
ventricular dissociation appeared (see Figure, c; superposition of P wave over
QRS ventricular complex is evident). After 2 min, the latter was replaced with
a "bottom" node rhythm (see Figure, d; negative P wave evident following QRS
complex). Onset of this rhythm disturbance can be explained as follows. At
the first stage of the effect of atropine (activation of vagal system), total
depression of sinus impulsation did not occur, there being merely mild slowing
with relatively high level of excitability of second-order centers of automa-
tims. As we know [6, 11], slowing of impulsation from the sinus mode activates
heterotopic automatism in secondary centers. In our case, further depression
of impulsation in the sinus node elicited brief (for 3 min) appearance of
"bottom" node rhythm. The beginning replacement of the "bradycarditic effect"
of atropine by its sympathetic effect led to restoration of nomotopic sinus
rhythm of the heart in the 21st min of the test (see Figure, e). On the whole,
the biphasic effect of atropine occurred in this group in 15 out of 17 men,
and the bradycarditic effect was manifested by slower heart rate in the range
of 2 to 12/min, while the tachycarditic effect in the second phase was manifested
by a 5-24/min increase, as compared to the baseline. In the subject with the
tendency toward resting tachycardia, the phase of rhythm slowing did not occur
during the atropine test; on the contrary, tachycardia increased, and the HR
increment constituted 15/min by the end of the test.

At rest, 23 out of the 25 men in the 2d group showed a proper sinus rhythm
before the atropine test, 1 presented moderate sinus bradycardia (HR 45-46/min)
and another demonstrated migration of rhythm within the oimits of the right
atrium during maximum inspiration. Analogous migration of rhythm recurred
in this subject from the 15th to 21st min of the test. We failed to demonstrate
any other rhythm disturbances whatsoever. A biphasic effect was observed in 18
out of the 25 men after injection of atropine: HR in the first phase showed
slowing of 2-22/min, while acceleration in the second phase constituted 5-25/min.
No biphasic effect was noted in seven subjects. In three of these cases there
was no bradycarditic effect and in four, no tachycarditic effect.

All 5 men in the 3d group showed a correct sinus rhythm before the atropine test.
No rhythm disturbances were demonstrable during the test. A biphasic effect of
atropine was found in 2 men and it was associated with 2-3/min slowing of
rhythm and 8-21/min acceleration. In the other 3 subjects, there was either
no bradycarditic effect (2 men) or no tachycarditic one (1 man).
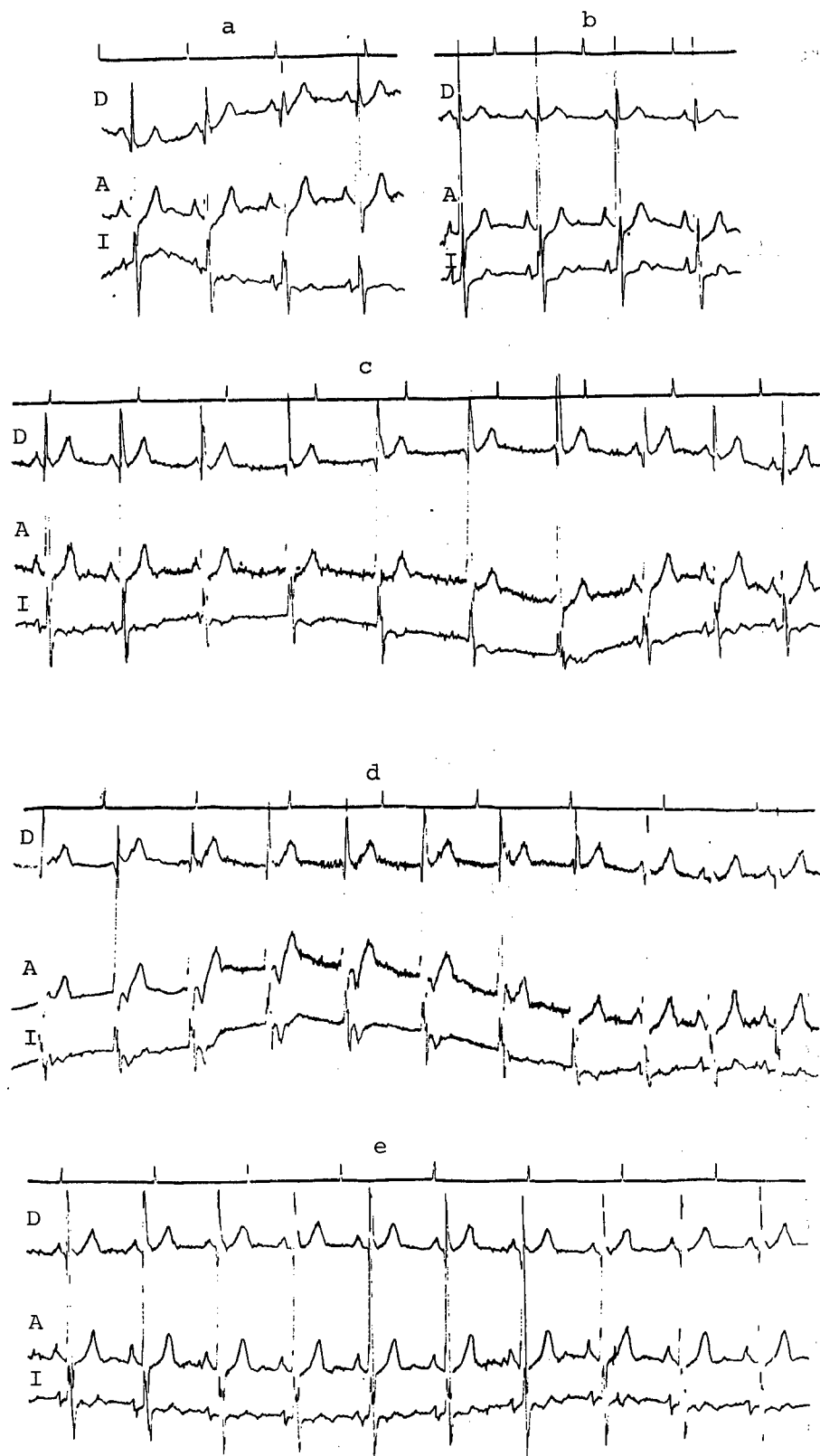
ECG of subject V., 32 years old, Nehb's D, A and I leads
a) at rest
b) at rest in maximum inspiration

c, d, e) at rest in 16th, 18th and 21st min, respectively, after hypodermic injection of atropine

Table 2. Dynamics of mean values of ECG parameters of men in different age groups under the effect of atropine

Subject group	Before atropine						Time after atropine, min 24 min		
	PQ	QT	SI(a)	SI(n)	ΔP_2	ΔT_2	PQ	QT	SI(a)
1	0,17 ±0,022	0,38 ±0,02	39,5 ±7,52	37,3 ±4,18	0,13 ±0,041	0,38 ±0,07	0,15 ±0,017*	0,37 ±0,03	38,5 ±6,05
2	0,16 ±0,02	0,37 ±0,03	40,5 ±4,83	38,9 ±2,80	0,15 ±0,03	0,32 ±0,09	0,14 ±0,015*	0,38 ±0,02	39,6 ±4,36
3	0,18 ±0,02	0,37 ±0,01	40,2 ±3,86	38,4 ±1,29	0,14 ±0,02	0,32 ±0,06	0,16 ±0,017*	0,37 0,01	40,8 ±3,86

Subject group	Time after atropine 24 min			60 min					
		ΔP_2	ΔT_2	PQ	QT	SI(a)	SI(n)	ΔP_2	ΔT_2
1	37,8 ±3,74	0,11 ±0,043	0,35 ±0,09	0,16 ±0,02	0,36 ±0,02	43,4 ±6,45*	40,4 ±3,8*	0,12 ±0,029	0,37 ±0,07
2	38,0 ±2,05	1,13 ±0,038	0,34 ±0,10	0,16 ±0,012	0,37 ±0,02	45,0 ±4,15*	41,1 2,85*	0,15 ±0,026	0,34 ±0,10
3	38,6 ±1,71	0,11 ±0,02	0,30 ±0,04	0,17 ±0,017	0,37 ±0,02	47,8 ±6,44	42,0 ±3,43*	0,11 ±0,043	0,28 ±0,09

The dynamics of time and amplitude parameters of the ECG were similar in all three groups in response to the atropine test (Table 2). However, there was a reliable variation under the influence of atropine in mean PQ interval (P<0.05) and systolic index (P<0.05). In the first phase, in the presence of slower rhythm, there was reduction of PQ interval by a mean of 0.02 s ($\Delta PQ = 0.01 - 0.03$ s); in the second half the test period, in spite of development of a tachycarditic tendency, PQ interval increased and toward the end of the test reached the baseline or differed from it by 0.01 s in most cases. During the test there was no appreciable change in electrical systole; nevertheless, in the second phase of the test, in the presence of increasing HR, there was a discrepancy between actual and nominal systolic indexes, which increased with age. In the baseline period, the difference in all groups constituted about 2%, by the end of the test it was 3% for the 1st group of subjects, 3.9% for the 2d and 5.8% for the 3d. This indicates that there is an increase in inertial force with age, and it is consistent with the opinion of a number of authors [2, 7] that biological processes slow down with aging. The amplitude of P and T waves, as well as QRS complex, did not change during the test, or else showed variations in the range of 0.5-1 mm. By the end of the test these changes usually disappeared. In spite of the similarity of changes in ECG and HR parameters, we found age-related differences in reactivity of the cardiovascular system to atropine. Thus, at a younger age, a biphasic effect of atropine, primarily manifestation of its first bradycarditic phase and possibility of appearance of heterotopic pacemakers, was observed more often than in older individuals, particularly over 50 years of age. This is

also confirmed by the more frequent appearance of rhtyhm migration upon forced breathing in young people (development of bradycardia effect). On the whole, this confirms once more the prevalence at a young age of parasympathetic influences on the heart. The diagnostic value of these data is obvious.

It is known that gerontologists [5, 8, 10] observe increase, with age, in sensitivity of chemoreceptors to various drugs, but their studies usually pertain to individuals over 60 years of age. Within the limits of the group we studied (25-59 years), such a pattern was not demonstrated, and this is very important to understanding of the age-related range of reactivity to vegetotropic and vasoactive agents.

The difference in dynamics of some parameters in response to atropine--slower build-up of adrenergic influence on the heart and some inertia in reduction of electrical systole in response to faster rhythm with increase in age--confirms once more the known pattern of slowing of biological processes as man ages.

The difference in direction of change in PQ interval under the effect of atropine (reduction with slower rhythm and, on the contrary, extension with appearance of tachycarditic tendency) is apparently related to the fact that, after giving atropine, the effect on the myocardium of the left and right vagi is not removed simultaneously [13]. There may also be another mechanism in the genesis of changes in PQ interval: the slower rhythm under the effect of atropine, which provides conditions for the myocardium, including the atrioventricular system, to "rest," accelerates local conduction. In the second phase, one observes the opposite effect, poorer conduction, apparently related to tachycardia [12].

Thus, it has been established that the test with hypodermic injection of atropine sulfate in therapeutic dosage helps demonstrate the autonomic "tendencies" of the human body and its predisposition for rhythm disturbances. In spite of the similarity of changes in ECG and HR parameters, it was shown that there are age-related changes in reactivity of the cardiovascular system to this product. Indeed, the biphasic effect of atropine, intensity of its bradycarditic phase and appearance of heterotopic pacemakers are observed more often in young people (25-39 years) than in older individuals, particularly after the age of 50. Subjects over 50 years of age demonstrate slower build-up of the adrenergic effect at the end of the atropine test and some inertia in reduction of electrical systole with build-up of HR, which is apparently attributable to slowing of biological processes with age.

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FLUID AND ELECTROLYTE CONTENT IN PREGNANT RATS AND THEIR OFFSPRING FOLLOWING FLIGHT ABOARD COSMOS-1514 BIOSATELLITE

[Article by Ye. I. Shakhmatova, Ye. A. Lavrova, Yu. V. Natochin, L. V. Serova and L. A. Denisova]

[English abstract from source] The female rats were flown on Cosmos-1514 for 5 days during gestation days 13 through 18. The rats showed a significant reduction of the Ca concentration in the liver and kidneys, its smaller decrease in the skin, and no changes in bones. The fetus weight decreased, its water content increased, and the content of Na, K, Ca and Mg remained unchanged. The 15- and 30-day pups of the flown rats did not exhibit any differences in the water and electrolyte content in bones, skin, liver or kidneys as compared to the controls. These data indicate that water and electrolyte homeostasis of growing fetuses was highly stable and the deviations that emerged under the influence of spaceflight factors on the mother-fetus system rapidly returned to the norm.

[Text] Adult mammals have highly efficient homeostatic mechanisms that provide for constancy of ion composition, osmolality, volume and pH of basic fluids in body spaces. In fetuses before birth and neonate mammals, electrolyte composition of blood plasma is virtually the same as in adult animals [12, 14]. This indicates that there are highly efficient systems of regulating fluid-electrolyte metabolism already at the end of the prenatal period and in the first few days of the postnatal period. The exceptionally important role of fluid and electrolyte metabolism in development of individuals and performance of various cell and organ functions warrants the belief that parameters of fluid-electrolyte composition of the body could be used as integral criteria of the state of developing organisms. The levels of electrolytes prevailing within cells (potassium, magnesium), extracellular fluid (sodium) and supporting tissues (calcium) can serve as an important indicator for evaluation of progress of embryonic development under extreme conditions. Our objective here was to characterize the effect of spaceflights on the condition of pregnant rats and their offspring at different stages of ontogenesis, according to fluid and electrolyte composition of the body and certain organs.

Methods

The study was conducted on 4-month rats from a Wistar population at the Stolbovaya Vivarium. The material was obtained in the course of a combined embryological experiment conducted aboard Cosmos-1514; the protocol of the experiment and its basic results were described previously [8].

The animals were on the biosatellite from the 13th to 18th days of gestation.

We used two control groups of rats kept under vivarium conditions and in a ground-based mock-up of the biosatellite (synchronous control), where the living conditions of the animals aboard the spacecraft were simulated, as well as physiologically relevant factors related to launching and landing (vibration, acceleration, impact accelerations) [7]. The animals of all three groups received a balanced diet in the form of soft feed (55 g/day) and water ad lib. [3].

Some animals were dissected on the 18th day of gestation. We took for examination pieses of bone (tibia), skin, kidney and liver of rats, as well as whole fetuses and placenta. Some rats were kept until natural labor occurred. Their offspring were examined at the age of 1, 15 and 30 days.

In order to determine fluid and dry matter content, the fetuses, placentas, neonate organs and pieces of organs from adult rats, which were protected against drying, were rapidly weighed on a VLAO-100 scale, placed on quartz slides and desiccated to a constant weight at 105°C. The specimens were then put in quartz test tubes, concentrated HNO_3 was added to them, and they were kept in an air-dry bath at 80°C until there was complete dissolution of organic matter, after which the acid was evaporated and samples diluted in distilled water. Sodium and potassium concentrations were measured on a Zeiss-III flame photometer in an air-propane flame; calcium and magnesium were measured in an air-acetylene flame on a Hitachi atomic absorption spectrophotometer, model 508. The results were processed using Student's t criterion.

Results and Discussion

During the spaceflight, fetal development was affected primarily with respect to its weight, which was almost 10% less than in synchronous control fetuses [8]. As compared to the synchronous control, dry matter of flight group fetuses weighed 12% less. These findings warrant the conclusion that spaceflight factors (primarily weightlessness) retarded formation of organic matter in fetuses. Since there was no difference between fetuses in the synchronous and vivarium controls with respect to this parameter, it can be concluded that other spaceflight factors did not affect weight gain in developing fetuses. Relative fluid content in fetuses of rats whose gestation period occurred in space not only failed to be diminished, but reliably exceeded this parameter in control animals (Figure 1).

Hydration of fetal tissues is one of the important criteria of embryonic development. It is known that a high water content in the fetus is considered a sign of its retarded development [4, 9]. The 6% greater hydration of fetuses in the flight group, as compared to the synchronous control, which we found

in our experiments, constitutes a 17-h delay in development, according to the age-related dynamics of rat fetus hydration [6], which corresponds to about 18 days in humans [5]. If the same evaluation is made of parameters of retarded weight gain, developmental retardatation in weightlessness would constitute about 5 h for rats and about 5 days for man.
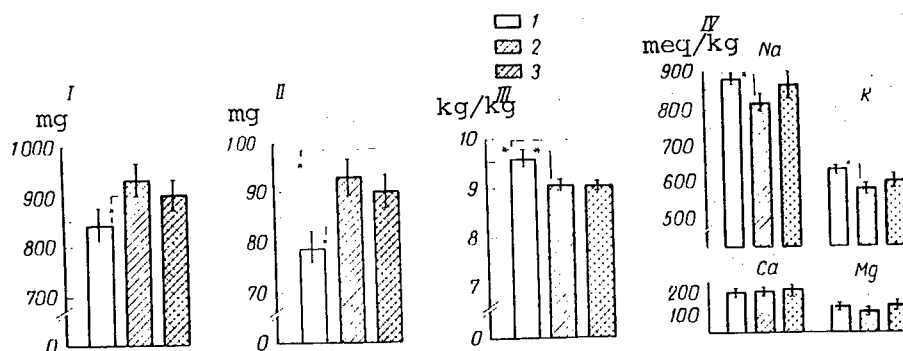

Figure 1. Dry matter, fluid and electrolyte content in 18-day rat fetuses

Here and in Figure 2, on y-axes:
  I) weight (mg)
 II) dry mass (mg)
III) H_2O (kg/kg dry matter)
 IV) electrolyte content (meq/kg dry matter)
    Asterisk indicates $P<0.05$ and a dot, $P<0.01$.

1) fetuses from animals exposed to weightlessness
2) synchronous control
3) vivarium control

Thus, according to the prevailing point of view, developmental retardation of fetuses in weightlessness does not occur due to extension of the process as a whole in time, but because of uneven retardatation in the course of development of different processes, systems and organs. This is also confirmed by the fact that sodium, potassium, calcium and magnesium content in wet substance of the fetal body in the flight group corresponded to chronological age and did not differ from the levels of these minerals in control group fetuses (see Table).

The obtained data are indicative of differences between the function of mechanisms that implement development of organic matter and fluid-electrolyte homeostasis. In spite of the decrease in amount of organic matter, electrolyte content and proportion between electrolytes is formed in fetuses with a relatively higher stability. This facts compel us to be cautious in using the criterion of increased hydration as an indicator of developmental retardation of fetuses. It is quite probable that the rate of fetal maturation in space does not differ from the ground-based control, nor does the actual program of development change, but for some reason (perhaps due to diminished placental transport, impaired metabolism in plasma or placenta) there is less synthesis of the organic constituents that are not absolutely necessary for normal fetal development.

In rats whose gestation period was spent in weightlessness, placenta weight and weight of its dry matter were lower than in the control groups of animals [8].

Fluid content of placenta was the same in all three tested groups, which is indicative of parallel formation of organic matter and accumulation of fluid in in this organ. However, there was a different correlation between sodium and potassium ions accumulated in the placenta, on the one hand, and organic matter, on the other, in the flight group of animals than in the controls: the share of sodium per unit dry matter was higher and that of potassium was lower (Figure 2). There were no such differences in bivalent ions. The decrease in potassium, which is a predominantly intracellular ion, in the placenta of flight group animals could be indicative of slower formation of cellular elements in it. This is confirmed by the results of histological examination [15], which revealed retardation of growth and branching of the labyrinthine zone of the trophoblast in the fetal part of the placenta.

Fluid content (g/g weight) and electrolytes (μeq/g weight) in wet matter of 18-day rat fetuses

Parameter	Tested group of rats		
	flight (n = 9)	synchronous control (n = 9)	vivarium control (n = 13)
Fetus			
Fluid	0,905±0,001	0,900±0,001	0,900±0,001
Sodium	82,9±1,3	81,4±1,0	85,4±2,9
Potassium	60,4±0,8	58,6±1,3	59,9±2,2
Calcium	19,9±1,9	21,6±1,6	22,9±2,4
Magnesium	13,0±0,3	12,4±0,5	14,9±1,9
Placenta			
Fluid	0,855±0,004	0,855±0,003	0,853±0,001
Sodium	72,5±1,6*	62,8±1,6	67,0±1,9
Potassium	56,7±0,9*	63,6±0,8	63,6±1,1
Calcium	5,6±0,6	5,9±0,8	7,6±1,1
Magnesium	10,3±0,3	10,2±0,3	11,0±0,3

*$P<0.001$, as compared to synchronous control.

n) number of animals
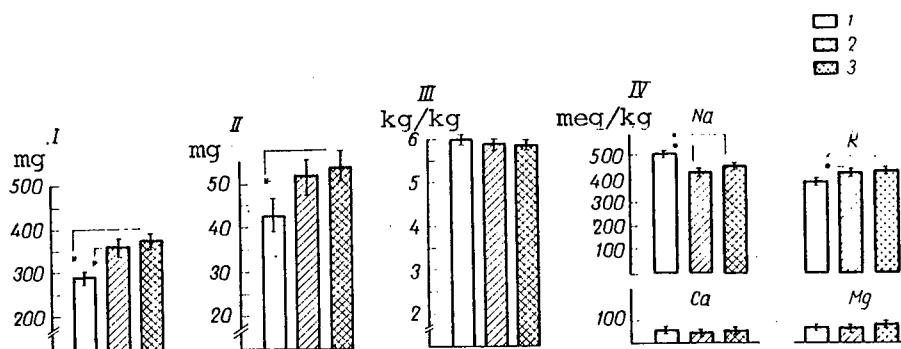
Figure 2. Dry matter, fluid and electrolyte content of rat placenta on 18th day of gestation period

Weight of rats flown in space in the gestation period constituted a mean of 293 g at the time of landing, weight gain during the flight did not exceed 5 g. In the same period, the weight of animals in the synchronous group increased by a mean of 65 g. Feed intake was virtually the same in these groups [8]. In view of the fact that the control group rats had an average of 1 fetus less, overall weight of term fetuses was virtually the same in all three groups. Consequently, wieght loss in the flight group of animals, which constituted 60 g, was referable to the maternal tissues. These findings indicate either that some of the substances of the maternal body are used to build fetuses during spaceflight, or else that there is accelerated metabolism in the cells of a number of organs, which is not compensated by feed intake. In particular, we were impressed by the lower weight of the liver in the flight group (10.3 g) than in the synchronous (14.6 g) and vivarium (13.4 g) control groups. Kidney weight did not decrease, constituting 1.86 g in the flight group, 1.93 and 1.94 g in the synchronous and vivarium groups, respectively [8].
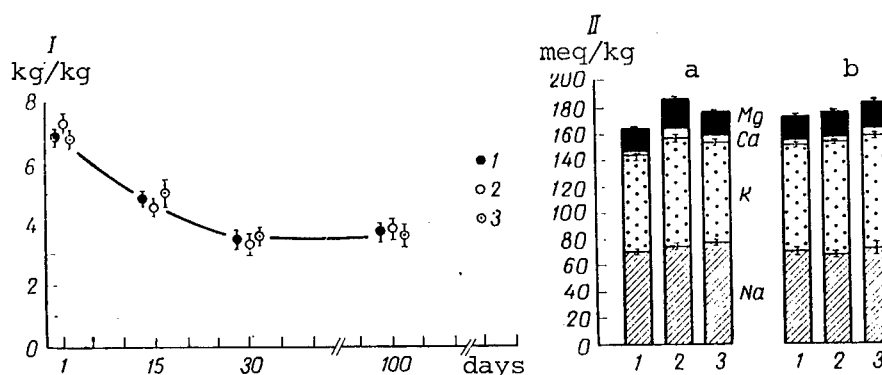
Figure 3. Fluid (I, in kg/kg dry matter) and electrolyte (II, meq/kg wet matter) content of kidney in rats of different age groups
X-axis: 1) pregnant animals exposed to weightlessness and their offspring
2) synchronous control
3) vivarium control
Electrolyte composition of kidneys is shown for 1st (a) and 15th (b) days after birth.

Thus, unlike ordinary conditions, when rats gain weight during the gestation period due to development of fetuses and fetal membranes, during flight aboard the biosatellite this did not happen. Analogous phenomena are observed under certain other extreme conditions. For example, in rats whose third trimester of pregnancy proceeded at hypergravity, weight virtually failed to increase, but a normal number of fetuses developed [10]. Consequently, organic and inorganic elements of the mothers served as an importance source in building the fetuses. This should have inevitably led not only to change in maternal weight, but redistribution of a number of substances (including electrolytes) between the mother and fetus.

Investigation of fluid and electrolyte composition of different organs and tissues of rats flown aboard Cosmos-1514 on the 18th day of the gestation period

revealed that electrolyte content remained virtually unchanged in the skin and bones of flight group animals. At the same time, the liver showed a substantial decrease in calcium content of dry residue and some increase in sodium content scaled to the unit of wet substances, whereas in the kidneys there was a decrease in sodium, potassium and calcium. A comparison of these data to the above-mentioned findings from the study of electrolyte composition of fetuses that developed during spaceflight enables us to discuss the question of mechanisms of providing an ion balance in pregnant animals and their fetuses. In wieghtlessness, fluid-electrolyte parameters were more stable in fetuses than their mothers. New data concerning the existence of independent mechanisms of providing mineral homeostasis in the fetus and mother could serve as an explanation of this finding. It was learned that, in the fetus, there is formation and functioning of a self-contained system for control of fluid-electrolyte metabolism. Thus, $1,25(OH)_2D_3$, parathyroid hormone and calcitonin, which are synthesized in the fetal endocrine system, participate in regulating fetal calcium balance. Secretion of hormones by the placenta and endocrine system of the mother provides optimum conditions for development of the fetus, in which there is a concurrently functioning self-contained system of regulating mineral homeostasis [13].
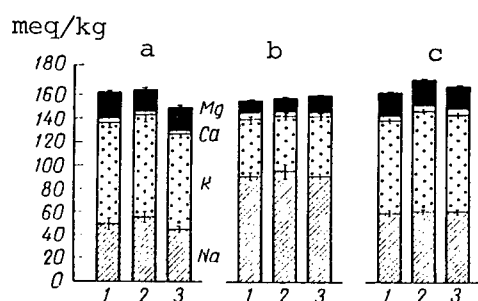
Figure 4.
Electrolyte content (meq/g wet substance) in liver (a), skin (b) and heart (c) of day-old rats
1) flight group
2) synchronous control
3) vivarium control

Determination was made of weight and fluid-electrolyte composition of some vital organs in day-old rats, part of whose prenatal period was spent in weightlessness. The obtained data indicate that there was no appreciable difference in levels of fluid and electrolytes in the liver, heart and skin (Figure 4). Kidney weight was higher in rats that developed in weightlessness, while its electrolyte content was lower than in control neonates.

Examination of 15-day rats revealed that kidney weight was virtually the same in all 3 groups. We failed to demonstrate differences either in fluid and electrolyte content of dry and wet matter in baby rats in the flight and control groups (Figure 3).

This conclusion can also be made with respect to electrolyte composition of the liver, skin and bones. Up to the 15th day, the baby rats consumed only maternal milk, so that the mineral composition, which depends on mineralization of the mother, affects fluid and electrolyte composition of offspring tissues. The fact that no significant deviation of mineral homeostasis of tissues was demonstrated in 15-day rats part of whose intrauterine development occurred in weightlessness indicates not only that there was proper formation and regulation thereof in the offspring, but some normalization of deviations found in the mothers right after the flight.

By the age of 30 days, baby rats are completely weaned and can live independently of their mothers. In expressly this period there could have been demonstrable latent defects in fine regulation and maintenance of homeostasis. However, a comparison of fluid and electrolyte composition of tissues in baby rats

of the flight and two control groups failed to reveal appreciable differences. Consequently, it can be concluded that development in weightlessness had no effect on the tested parameters of fluid and electrolyte homeostasis.

The results of studies of the effects of spaceflights on fluid-electrolyte metabolism indicate that, depending on duration of the flight, there are changes in different forms of ion metabolism and renal reactions to hormones in man [1, 2] and animals [11]. A comparison of these results to our findings here indicates that there is a high degree of integrity of the system of fluid and electrolyte homeostasis in developing fetuses of white rats and rapid repair in them of deviations that arose as a result of exposure of the mother-fetus system to spaceflight factors.

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EFFECT OF DIPHOSPHONATES ON DEVELOPMENT OF OSTEOPOROSIS IN HYPOKINETIC RATS

[Article by A. S. Kaplanskiy, G. N. Durnova, Z. F. Sakharova, and B. V. Morukov]

[English abstract from source] Using histomorphometric
methods, the effect of diphosphonates (hydroxydimethylamino-
propylene diphosphonic acid and hydroxyethylene diphosphonic
acid) on the development of osteoporosis in spongy matter of
tibia and vertebrae of the rats exposed to hypokinesia for
60 days was investigated. It was found that aminoprophlene
diphoshonic acid in the dose 6 mg phosphorus/kg/day prevented
osteoporosis and caused an increase in the volume density and
abnormal (cartilage rich and poorly ossified) spongy bone.
By contrast, ethylene diphosphonic acid in the dose 9 mg
phosphorus/kg/day did not prevent osteoporosis but reduced its
severity.

[Text] The beneficial response obtained with diphosphonate in the treatment of
osteoporosis in man [1, 7, 8], as well as experimental data indicative of in-
hibited bone resorption in animals given diphosphonates [4-6], warrant the be-
lief that these synthetic analogues of pyrophosphates can be used to prevent
osteoporosis, which develops during hypokinesia and exposure to weightlessness.
We submit here the results of administering hydroxydimethylaminopropylene di-
phosphonic acid (AMOK)* and hydroxyethylene diphosphonic acid (OEDF) on develop-
ment of osteoporosis in rats submitted to clinostatic hypokinesia.

Methods

The study was pursued on 17 male Wistar rats with base weight of 240-290 g. The
experimental groups of rats were placed in box-cages for 60 days. They were
given AMOK or OEDF daily, per os, in doses of 6 and 9 mg phosphorus/kg, res-
pectively. As a control we used intact rats (vivarium control--VC) and rats
submitted to hypokinesia (hypokinetic control--HC) without giving them any
product. We also examined rats kept under ordinary vivarium conditions which

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*This product was synthesized by Academician M. I. Kabachnik at the Institute
 of Elementoorganic Compounds imeni Academician A. N. Nesmeyanov, USSR Academy
 of Sciences.

were given AMOK or OEDF daily in the same dosage as animals in the experimental groups. After completion of the experiment, the rats were weighed, length of their tail was measured (tail length is one of the indicators of linear growth of rats) and then they were decapitated. The tibia and lumbar spine were cleared of muscles, length of the tibia was measured with calipers, then the bones were fixed in 4% neutral formalin prepared with 10% EDTA = Na_2 (pH 7.0). The bones were decalcified in 10% EDTA = Na_2, thoroughly washed in water and imbedded in histoplast. Serial bone sections 5 µm in thickness were stained with hematoxylin and eosin, picrofuchsin, methyl green-pyronine, alcian blue and toluidine blue. The stained sections were used for microscopic and quantitative histomorphometric studies. Using the dot method with the morphometric grid of S. B. Stefanov, we determined volume density of primary and secondary spongiosa, and with an MOV-15 ocular micrometer we measured the width of the epiphysial cartilaginous growth plate and width of the primary spongiosa zone. Osteoblasts and osteoclasts in 20 fields were counted at microscope magnification of 630 . The data were submitted to statistical processing according to Student, considering differences reliable at $P < 0.05$.

Results and Discussion

According to the data listed in Table 1, intake of AMOK and OEDF by normal rats had no effect on their weight, height and length of tibia. Administration of diphosphonates to intact rats led to substantial changes in bone structure. Thus, in rats given AMOK, there was an increase in volume density of primary spongiosa of the tibia and lumbar vertebrae, as well as inwidth of the epiphysial cartilaginous growth plate and primary spongiosa zone (Tables 2 and 3). There was also a change in structure of osseous trabeulae under the effect of AMOK. While cartilage was demonstrable in intact rats in the form of a narrow band only in the center of the trabeculae and their periphery consisted of newly formed bone, the reverse was observed in rats given AMOK. The wide central part of the trabeculae consisted of cartilage rich in acid mucopolysaccharides, whereas along the periphery there was a narrow band of bone tissue. The number of active osteoblasts (polygonal cells with extensive cytoplasm, rich in ribonucleoproteins and eccentircally situated nucleus) dropped dramatically in the primary spongiosa zone of the tibia and vertebrae when rats were given AMOK. At the same time, the number of osteoclasts increased, and giant polynuclear cells with moderately pyroninophilic cytoplasm were encountered more often among them, which lay freely in the intertrabecular spaces (see Tables 2 and 3). Volume density of tibial and vertebral secondary spongiosa did not change under the influence of AMOK. Excessive development of primary spongiosa in the bones of rats given AMOK is apparently related primarily to inhibited bone resorption as a result of impaired osteolytic function of osteoclasts under the effect of diphosphate [9-11]. Inhibition of bone resorption led to impairment of the normal remodeling process in bones and appearance of disproportion between primary and secondary spongiosa. The depression of osteolytic function of osteoclasts under the effect of AMOK was so profound that it was not compensated by an increase in number of these cells. Diminished rate of trabecular ossification was the result of decrease in number of osteoblasts, which produce procollagen.

Thus, administration of AMOK to rats, though it did cause an increase in volume density of primary spongiosa of bones, resulted in qualitative difference of

de novo bone, as compared to normal, and mineralization of such bone tissue could be impaired.

Table 1. Effect of diphosphonates on weight, length of tail and tibia of rats submitted to 60-day hypokinesia

Rat group	Weight, g		Length of tail at end of exp., mm	Length of tibia at end of exp., mm
	at start of experiment	at end of experiment		
VC	243±11,4	322±8,8	166,8±2,4	39,3±0,4
VC+OEDF	258±10,6	359±15,0	168,0±3,7	40,4±0,5
VC+AMOK	293±12,1	353±13,0	168,0±3,9	39,7±0,3
HC	252±9,3	229±5,1*	160,6±1,4*	37,7±0,3*
HC+OEDF	265±6,6	225±9,0*	155,6±5,0*	38,0±0,2*
HC+AMOK	269±7,9	224±8,0*	159,7±2,9	36,3±0,4*'**

Note: Here and in Tables 2 and 3, one asterisk indicates reliability of differences in comparison to VC parameters and two asterisks, the same in relation to HC values.

Table 2. Effect of diphosphonates on histomorphometric parameters of rat tibia with exposure to 60-day hypokinesia

Group	Width, µm		Volume density, %		Cells per field	
	growth plate	primary spongiosa	primary spong.	secondary spongiosa	osteo-blasts	osteo-clasts
VC	153±3,0	322±48,0	38±1,44	18±0,81	25,60±0,13	1,96±0,13
VC+OEDF	157±6,0	322±17,0	44±1,00*	28±2,88*	24,75±2,36	2,92±0,25*
VC+AMOK	191±9,0*	1926±116*	56±1,25*	16±0,75	11,60±2,20*	2,64±0,15*
HC	127±8,0*	186±18,0*	18±0,75*	8,0±0,63*	13,07±1,79*	2,38±0,20
HC+OEDF	115±6,0*	108±8,0*,**	13±0,63*,**	11±0,63*,**	7,08±1,87*,**	1,86±0,32
HC+AMOK	158±3,0**	1067±50*,**	51±1,13*,**	15±1,13*,**	7,43±0,88*,**	2,71±0,21*

Table 3. Effect of diphosphonates on histomorphometric parameters of lumbar vertebrae of rats submitted to hypokinesia for 60 days

Group	Width, µm		Volume density, %		Cells per field	
	growth plate	primary spong.	primary spongiosa	secondary spongiosa	osteo-blasts	osteo-clasts
VC	104±0,9	282±38,0	15,0±0,45	6,9±0,48	11,3±1,85	1,84±0,25
VC+OEDF	110±1,4*	437±31,5*	15,3±0,47	8,1±0,40*	11,4±0,70	1,62±0,17
VC+AMOK	123±2,1*	531±48*	19,9±0,34*	6,8±0,65	9,6±0,75*	2,24±0,14*
HC	90±1,8*	89,0±9*	9,3±0,35*	5,4±0,35*	7,24±1,05*	0,75±0,06*
HC+OEDF	93±1,0*	93±9*	8,9±0,41*	7,2±0,54**	7,00±1,93*	0,80±0,09*
HC+AMOK	107±1,4**	384±48**	18,2±0,33**	6,3±0,46	7,3±1,3*	2,17±0,16**

Administration of OEDF to intact rats had a considerably smaller effect on bone than AMOK. Thus, an increase in width of cartilaginous growth plate and primary spongiosa zone was noted only in the lumbar vertebrae. Volume density of primary and secondary spongiosa increased more in the tibia and less in vertebrae; the number of active osteoblasts did not change, while the number of osteoclasts increased only in the tibia (see Tables 2 and 3). On the whole, the impression was gained that administration of OEDF to intact rats elicits some inhibition of bone resorption and has no appreciable effect on bone growth or de novo osteogenesis.

The data listed in Table 1 indicate that hypokinesia leads to weight loss and inhibition of growth of rats.

Histological and morphometric studies of the tibia and lumbar vertebrae established that restriction of animal movement elicits development of osteoporosis, as indicated by the decrease in volume density of spongy bone (see Tables 2 and 3). The investigations of other authors [2, 3] have also shown development of osteoporosis in hypokinetic rats. Osteoporosis which developed under hypokinetic conditions was based on inhibition of bone growth and de novo osteogenesis, as indicated by the decrease in length of thetibia, width of the cartilaginous growth plate and zone of primary spongiosa, as well as in number of active osteoblasts in the zone of primary spongiosa. Evidently, there was no appreciable change in the process of bone resorption under hypokinetic conditions, since there was insignificant increase in number of osteoclasts in the tibial bones, whereas in the lumbar vertebrae it decreased somewhat (see Tables 2 and 3).

Preventive administration of AMOK to hypokinetic rats had no beneficial effect on weight gain or growth of the animals (see Table 1), and at the same time it increased volume density of primary and secondary spongiosa. Volume density of secondary spongiosa was closed to that of VC rats, while volume density of primary spongiosa was considerably higher than in VC (see Table 2). The width of the cartilaginous growth plate of animals given AMOK under hypokinetic conditions did not differ from that of VC animals, while the width of the primary spongiosa zone was greater than the analogous parameter in VC. The number of active osteoblasts in the primary spongiosa zone decreased to 1/2 and 1/4 of the values for HC and VC, respectively, while the number of osteoclasts increased (see Table 2). The increase in width of the epiphysial cartilaginous growth plate occurred due to thickening of the zone of cartilage erosion, as well as of the zone lying above the columns of cartilage cells, whereas the height of cartilaginous cell columns diminished, which was quite consistent with the reduction in length of tibial bones and was indicative of inhibition of their growth. Thus, administration of AMOK to hypokinetic rats inhibited growth and resorption of bone, but since bone resorption was more inhibited that its growth, there was increase in volume density of spongy bone.

Administration of OEDF to rats, like AMOK, failed to affect growth rate or weight gain, which remained the same as in animals submitted to hypokinesia but not given any diphosphonate (see Table 1). Microscopic and morphometric analyses revealed that the reactive changes in lumbar vertebrae and tibial bones in response to OEDF are somewhat different. Thus, intake of OEDF led to an increase in volume density of only the secondary spongiosa of lumbar

vertebrae. Volume density of primary spongiosa, width of cartilaginous growth plate and zone of primary spongiosa, as well as number of osteoblasts and osteoclasts, did not change, and were the same as in HC rats (see Table 3). Unlike the vertebrae, the tibial bones of hypokinetic rats given OEDF showed a decrease in volume density and width of primary spongiosa, as compared to VC and HC. The decrease in volume density of pirmary spongiosa corresponded well to the decrease in number of active osteoblasts (see Table 2). Volume density of secondary spongiosa increased with intake of OEDF, as compared to HC, but still did not reach the level inherent to VC rats. There was the same number of osteoclasts as in VC. Thus, in rats submitted to hypokinesia, intake of OEDF elicited predominantly inhibition of bone resorption in the vertebrae, whereas in the tibial bones, along with inhibited bone resorption, we observed some depression of de novo osteogenesis. The causes of these differences are not clear. It may be that they are attributable to the difference in growth and bone metabolism rate, as well as in the loads to which bones are submitted.

Thus, preventive administration of AMOK in a dosage of 6 mg phosphorus/kg weight per day to hypokinetic rats prevented development of osteoporosis and led to development of bone tissue, which differed from normal spongy bone in that it contained excessive cartilage and presented poor ossification. Administration to rats of OEDF in a dosage of 9 mg phosphorus/kg/day did not prevent development of osteoporosis in rats submitted to hypokinesia, although it did attenuate its severity.

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INVESTIGATION OF INCIDENCE OF MORPHOLOGICAL CHANGES IN RAT CEREBRAL CORTEX
NEURONS UNDER THE EFFECT OF ACCELERATED CARBON IONS

[Article by B. S. Fedorenko, R. A. Kabitsyna, G. N. Krivitskaya, V. I.
Derevyagin, and N. I. Ruzhov]

[English abstract from source] Structural lesions in neurons
of the brain cortex of rats were investigated 1 and 3 months
after their exposure to accelerated carbon ions with the energy
320 MeV/nuclon 10^4 particles/cm^2 (LET = 120 MeVcm^2/g) as well
as to gamma-radiation in the dose 1.0 Gy. The irradiated ani-
mals showed morphofunctional, dystrophic and reparative lesions
in neurons. The rats exposed to carbon ions developed more dis-
tinct changes than the animals exposed to gamma-radiation. It
is postulated that similar fluxes of cosmic radiations will not
produce a deleterious effect on the integrative functions of
the central nervous system of cosmonauts.

[Text] Several experiments in balloons and artificial earth satellites involv-
ing detection of cosmic particles in the hit range by means of photographic
emulsions established that there is damage to cells or their structures as a
result of hits by heavy nuclei of galactic cosmic radiation (GCR). At the same
time, the disturbances demonstrated in plant systems were considerably more
marked than could have been expected from a hit by a single heavy nucleus. In
addition, the lesions were found in cells through which heavy nuclei did not
pass, as demonstrated on photographic emulsion [4]. This led to performance of
experiments on an accelerator of high-energy charged particles. The purpose of
these studies was to determine the deleteriousness of low fluxes of accele-
rated carbon ions with energy of 320 MeV/nucleon to rat cerebral cortex neurons.
The studies were pursued in a comparative aspect. In different variants of
the experiment, animals were exposed to carbon ions and ^{60}Co γ-radiation, the
dosage of which was about 100 times higher than that of carbon ions.

Methods

Experiments were performed on adult Wistar male rats divided into four groups.
The 1st group was exposed to accelerated carbon ions (LET = 120 MeV·cm^2/g) at
flux intensity of 10^4 particles/cm^2; the 2d group was exposed to γ-radiation
in a dosage of 1.0 Gy (dose rate 0.024 Gy/s) and 1 day later to a beam of carbon

ions, and the 3d to γ-radiation in a dosage of 1.0 Gy; the 4th group of animals constituted the control. Rats were exposed to carbon ions on a synchrophasotron of the Joint Institute for Nuclear Research in Dubna, and to γ-radiation from an RKh-γ-30 unit. The animals were decapited 1 and 3 months after exposure to radiation. Brain tissues were fixed for light microscopy by perfusion with formalin, methyl alcohol and acetic acid (1:8:1). The cerebral hemispheres were imbedded in paraffin blocks. Histological sections were stained with cresyl violet by the Nissl method. Quantitative analysis was made of structural lesions in cortical neurons. We analyzed 3000 neurons, among which 3 groups of cells were differentiated, from each animal: unchanged neurons, neurons with readily reversible changes (morphofunctional and compensatory-adaptive changes) and neurons with dystrophic disturbances, including irreversible necrobiotic and necrotic changes. We determined the percentage of cells of each group in the total number of neurons. In addition, we calculated the profile field of the body and nucleus of cells in the 5th cortical layer (Betz cells), the nuclus/cytoplasm ratio and glioneuronal index.

Results and Discussion

Examination of microscopic preparations of the rat brain 1 and 3 months after exposure to radiation enabled us to demonstrate impairment of cytoarchitectonics in the cerebral cortex, which consisted of appearance of small foci of cell depletion in the 2d and 3d cortical layers. We were impressed by the increased number of neurons close to one another, cells with enlarged clumps of basophilic substance, neurons with 2 and 3 nucleoli, more marked in the 1st group of animals. The structural lesions in brain tissue become somewhat localized 3 months after irradiation, we demonstrated more often neurons with signs of chromatolysis, vacuolization of cytoplasm and clumped dissociation of basophilic substance, cytolysis, neuronophagia, indicative of progressive dystrophic disturbances (Figure 1). There was typical arrangement of destructively altered cells around dilated capillaries with swollen endothelial nuclei and plasmorrhagia.

The above neuronal changes were also demonstrable in subcortical structures, the cerebellum and brain stem.

Distinct differences were demonstrable in different animal groups with respect to morpnological changes in cortical neurons upon quantitative analysis of the number of dystorphically altered cells. One month after irradiation, a larger number of dystrophic neurons was noted in the 1st and 2d groups of rats (see Table). It was 3 times more than the number of such neurons in the 4th group and twice as high as in the 3d group. Three months after irradiation (see Table), there was a tendency toward decrease in number of dystrophically altered neurons; however, the same quantitative ratio remained between neurons in the different experimental variants (Figure 2). There were more slightly altered neurons (11.3%) 1 month after irradiation in the 2d group of animals, whereas in other groups the number held at the same level. This was also inherent in unchanged neurons. After 3 months, all groups of animals showed a decrease in number of mildly altered neurons, which cam close to the control level. There were differences in profile field of the body and nucleus of cells 1 month after exposure to carbon ions, as well as γ-radiation and carbon ions. In the 2d group, the profile field of the neuronal body and nucleus was one-half the value of other groups, including the 4th. In the 3d group,

the profile field of the cells increased, whereas the profile field of the nucleus decreased. These parameters determined the corresponding values for nucleus-cytoplasm ratios.

Quantitative analysis of structural changes in neurons of rat cerebral cortex 1 and 3 months after exposure to accelerated carbon ions and γ-radiation

Animal group	Unchanged neurons, %	With slight changes, %	With dystroph. changes, %	Profile field of cell, μm²	Profile field of nucleus, μm²	Nucleus-cytoplasm ratio	Glio-neuronal index
After 1 month							
1	85,9±0,6	8,7±0,4	5,4±0,4	206,3±26,5	122,5±18,4	1,7±0,1	1,30±0,02
2	82,2±0,7	11,8±0,6	6,0±0,4	108,1±6,1	76,2±5,7	1,5±0,1	1,37±0,15
3	87,2±0,6	9,0±0,5	3,8±0,3	257,9±30,6	118,9±10,6	2,2±0,2	1,99±0,66
4	89,1±0,6	8,7±0,5	2,2±0,5	218,8±24,0	131,0±15,1	1,7±0,1	1,92±0,07
After 3 months							
1	88,9±0,5	6,9±0,5	4,2±0,3	185,4±12,4	134,1±8,1	1,4±0,6	2,01±0,01
2	88,9±0,6	5,1±0,4	5,0±0,4	172,6±24,2	108,2±16,5	1,6±0,1	1,85±0,04
3	92,3±0,5	5,2±0,4	2,5±0,3	248,5±11,8	133,7±11,8	1,8±0,8	1,88±0,07
4	92,3±0,5	5,4±0,4	2,3±0,3	218,8±15,1	131,1±15,1	1,7±0,8	2,00±0,06

We were impressed by the fact that there was some decline of nucleus-cytoplasm ratio in the 2d group of animals in the presence of considerably more diminished profile filed of cells and nucleu. This is indicative of rather high functional state of neurocytes. The 3d group of animals showed an increase in the nucleus-plasma ratio, which was indicative of diminished functional activity of cells.

The 1st group of rats showed a decline of nucleus-cytoplasm ration 3 months after exposure to radiation. It can be assumed that there was intensification of compensatory processes in neurons of this group of animals. This is also indicated by the rise of glioneuronal index 3 months after irradiation, as compared to values at earlier observation stages.

Thus, the results of our studies are indicative of the greater biological effectiveness of accelerated carbon ions, as compared to γ-radiation.

Analysis of the demonstrated morphological disturbances enables us to make a distinction between three groups of changes: morphofunctional disturbances (marginal location of enlarged clumps of cytoplasmic substance, moderate chromatolysis, hypertrophy of nucleus and nucleolus); dystrophic changes (total chromatolysis, vacuolization of cytoplasm, reduced size of nucleus and its vacuolization, chromatin deficiency, sites of cellular depletion, etc.); repair processes (enlargement of nuclei, nucleolus and cytoplasm due to enrichment of these structures with basophilic substance, presence of cells with two and three nucleoli).

Figure 1. Morphological changes in neurons 3 months after exposure to
carbon ions. Nissl stain, magnification 10×60

a) unchanged neurons in nonirradiated animal
б) swelling of neuronal bodies and neurons, segmented hyperchromatosis com-
bined with segmented chromatolysis, clearing of nuclei due to chromatin loss
в) pericellular edema, clumped disintegration of Nissl substance, ectopic
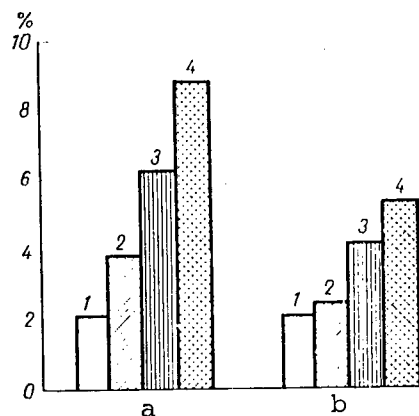nuclei, emission of nucleolar clumps

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Figure 2.
Number of dystrophically altered
neurons in rat cerebral cortex
1 (a) and 3 (b) months after
irradiation
1) nonirradiated animals
2) γ-radiation, 1.0 Gy
3) carbon ions, 10^4 particles/cm^2
4) γ-radiation and carbon ions

The change in cell volume is indicative of high functional activity of neurocytes in irradiated animals. We are referring here to hypertrophy of cells, which is based on intracellular hyperplasia aimed at restoration of impaired functions, At the same time, dystrophic changes occur in the hypertrophic cell at a certain stage and, in spite of the fact that it remains larger in volume, decompensation may occur. The rise of the glioneuronal index can be interpreted as the tangible basis of rapid function of both preserved structures and those formed in the repair process. Concurrently, this parameter may be a sign of neuronal death, which would be followed by neuronophagia [3]. These theses can be applied entirely to the demonstrated structural neuronal changes in the rats used in our experiments.

As for the causes of the greater biological effectiveness of low fluxes of heavy nuclei, in this case one should consider the possibility of neuronal activation, not only as a result of a direct hit by heavy particles. Thus, extended fragmentation and formation of cysts in brain tissue were demonstrated in Drosophila melanogaster 35 days after exposure to argon ions (^{40}Ar) at energy of 4.8 MeV/nucleon [6]. With one hit per two cells or one hit per 90 cells, there was swelling of neuronal cytoplasm and fragmentation of membranes. With a particle flux ranging from 1 hit per 6 cells to 1 hit per 135 cells, there was an increase in number of glial cells around the neurons in which dystrophic changes had occurred. The increase in biological effectiveness could be related to the influence of high-energy σ-electrons which extend over a greater area than the track from a primary particle. Although effectiveness should be greater in the center of the track than with σ-electrons, the probability of a heavy particle hitting a critical cellular structure is lower than interaction with far-reaching σ-electrons. These assumptions are confirmed by estimates made on the basis of experiments involving exposure of Chinese hamster cells to uranium ions with energy of 90 MeV/nucleon [5]. They can explain onset of damage in plant cells, which were not hit by heavy galactic cosmic radiation nuclei. One should also take into consideration processes of interaction between accelerated charged particles and biological tissue that are unrelated to the ionization effect, in particular, the effects of acoustic and inpact waves that arise when the matter in the track of the charged particle is heated and its aggregate state is altered [2]. The definitive role of Vavilov-Cherenkov luminescence, the intensity of which increases with increase in energy of multicharge ions, has not been established [1].

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THERMODYNAMIC STATE OF MULTICONSTITUENT $CO_2=CO=H_2O=H_2=N_2$ GAS MIXTURE IN ELECTROLYZER WITH SOLID ELECTROLYTE

[Article by B. G. Grishayenkov and N. G. Zorina]

[English abstract from source] The thermodynamic state of the gas mixture $CO_2 = CO = H_2O = H_2 = N_2$ in the cathode space of the electrolyzer containing a solid electrolyte is investigated. Calculation of the thermodynamic state makes it possible to determine the theoretical voltage of decomposition and concentration of individual components of this mixture at the outlet of the electrolyzer or each electrolytic cell as applied to various modes of operation. Knowledge of these parameters is important to build a technological scheme of a gas mixture regeneration system. Equations of four independent reactions are used to describe thermodynamic equilibrium of the gas mixture. Particular cases that occur, when one, two or more conditions of the technological process are not satisfied, are considered.

[Text] It is of considerable interest to investigate thermodynamic equilibrium of a $CO_2 = CO = H_2O = H_2 = N_2$ gas mixture in the cathode space of an electrolyzer with solid electrolyte in order to assess its efficiency.

The process of electrolysis of CO_2 and H_2O molecules in an electrolyzer with solid electrolyte depends on the baseline state of the tested gas mixture. In a stationary state (without electrochemical process), the thermodynamic state of the mixture is characterized by the following catalytic reactions:

$$CO_2 + H_2 \rightleftharpoons CO + H_2O,$$
$$CO_2 + 4H_2 \rightleftharpoons CH_4 + 2H_2O,$$
$$CO_2 + 2H_2 \rightleftharpoons C + 2H_2O,$$
$$H_2O \rightleftharpoons H_2 + {}^{1}/_{2}O_2, \quad CO_2 \rightleftharpoons CO + {}^{1}/_{2}O_2.$$
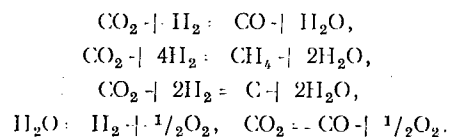
These catalytic reactions will have a certain effect on the electrochemical process (in particular, in carbon formation) localizing delivery of reagents to the zone of the electrochemical reaction.

The results of studies of thermodynamic state of the above gas mixture have been reported previously. Here, we offer a description of equilibrium of the gas mixture in the cathode space of an electrolyzer with solid electrolyte.
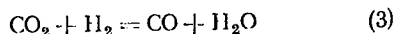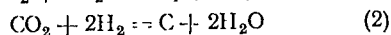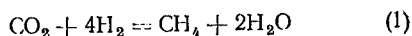
Thermodynamic Analysis of $CO_2 = CO = H_2O = H_2 = N_2$ Gas Mixture in Cathode Space of Electrolyzer With Solid Electrolyte

Of the entire diversity of substances consisting of atoms of H, C and O, it is sufficient to consider the presence or formation of the following in analysis of thermodynamic equilibrium of a reaction mixture in the cathode space of an electrolyzer operating at temperatures of 800–1000°C: CO_2, CO, C_{sol} [solid], CH_4, H_2O, H_2, O_2. For a thorough examination, we should add to these inert gas, presence of which in the reaction mixture would shift the equilibrium of reactions that occur with change in volume.

Calculation of thermodynamic equilibrium of $CO_2 = CO = H_2O = H_2 = N_2$ mixture for different modes of electrolyzer operation enables us to determine the theoretical energy of dissociation and concentration of the different constituents at the outlet of the electrolyzer (or each of its cells), knowledge of which is needed to design the variant in question of a system for regeneration of oxygen. The latter is feasible by virtue of the fact that the high temperature and presence of surfaces that have a catalytic effect should be instrumental in reaching thermodynamic equilibrium.

To describe thermodynamic equilibrium of the tested gas mixture, one must consider equations for four independent reactions, since the difference between the number of substances and number of atoms of which they consist equals 4.

We select the following as such a system:

$$CO_2 + 4H_2 = CH_4 + 2H_2O \qquad (1)$$
$$CO_2 + 2H_2 = C + 2H_2O \qquad (2)$$
$$CO_2 + H_2 = CO + H_2O \qquad (3)$$
$$H_2O = H_2 + \tfrac{1}{2}O_2 \qquad (4)$$
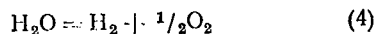
Let N_i^0 be the baseline concentrations (molar shares) of reagents. Let us introduce the following designations:

$$N_{H_2}^0/N_{CO_2}^0 = \alpha, \quad N_{CH_4}^0/N_{CO_2}^0 = \beta,$$
$$N_{H_2O}^0/N_{CO_2}^0 = \delta, \quad N_{CO}^0/N_{CO_2}^0 = \gamma,$$
$$N_{N_2}^0/N_{CO_2}^0 = \sigma \qquad (5)$$

We assume that $N_{O_2}^0 = 0$.

Since $\sum N_i^0 = 1$, we shall have:

$$N_{CO_2}^0 = \frac{1}{1+S}, \qquad N_{H_2}^0 = \frac{\alpha}{1+S}, \qquad (6)$$

$$N_{CH_4}^0 = \beta, \quad N_{CO}^0 = \frac{\gamma}{1+S}, \qquad N_{H_2O}^0 = \frac{\delta}{1+S},$$

$$N_{N_2}^0 = \frac{\sigma}{1+S}, \qquad (7)$$

$$S = \alpha + \beta + \gamma + \sigma + \delta.$$

Proceeding from 1 mol CO_2, let us assume that x_1, x_2 and x_3 are amounts of CO_2 that reacts according to equations (1), (2), (3), while x_4 is the amount of H_2O that reacts according to equation (4). Then, as a result of the reactions for each gas, we shall have:

$$S = \alpha + \beta + \gamma + \sigma + \delta$$
$$(1 - x_1 - x_2 - x_3) \text{ for } CO_2$$
$$(\delta + 2x_1 + 2x_2 + x_3 - x_4) \text{ for } H_2O,$$
$$(\alpha - 4x_1 - 2x_2 - x_3 + x_4) \text{ for } H_2,$$
$$(^1/_2 x_4) \text{ for } O_2$$
$$(\beta + x_1) \text{ for } CH_4 \quad (\sigma) \text{ for } N_2$$
$$(\gamma + x_5) \text{ for } CO \qquad (8)$$
$$\sum = 1 + S + 2x_1 - x_2 + {}^1/_2 x_4$$

Equivalent concentrations N_i, determined by the following equations:

$$N_{CO_2} = \frac{1 - x_1 - x_2 - x_3}{1 + S - 2x_1 - x_2 + 0,5x_4},$$

$$N_{H_2O} = \frac{\delta + 2x_1 + 2x_2 + x_3 - x_4}{1 + S - 2x_1 - x_2 + 0,5x_4},$$

$$N_{N_2} = \frac{\alpha - 4x_1 - 2x_2 - x_3 + x_4}{1 + S - 2x_1 - x_2 + 0,5x_4},$$

$$N_{O_2} = \frac{0,5x_4}{1 + S - 2x_1 - x_2 + 0,5x_4},$$

$$N_{CH_4} = \frac{\beta + x_1}{1 + S - 2x_1 - x_2 + 0,5x_4},$$

$$N_{N_2} = \frac{\sigma}{1 + S - 2x_1 - x_2 + 0,5x_4}, \qquad (9)$$

$$N_{CO} = \frac{\gamma + x_3}{1 + S - 2x_1 - x_2 + 0,5x_4},$$

are related by the following equations of thermodynamic equilibrium:

$$K_1 P^2 = \frac{(N_{H_2O})^2 (N_{CH_4})}{(N_{CO_2}) (N_{H_2})^4},$$

$$K_3 = \frac{(N_{CO}) (N_{H_2O})}{(N_{CO_2}) (N_{H_2})},$$

$$K_2 P = \frac{(N_{H_2O})^2}{(N_{CO_2}) (N_{H_2})^2},$$

$$K_4 P^{1/2} = \frac{(N_{H_2}) (N_{O_2})^{1/2}}{(N_{H_2O})}, \qquad (10)$$

where P is total pressure, or with consideration of (9):

$$K_1 P^2 = \frac{(\delta + 2x_1 + 2x_2 + x_3 - x_4)^2 \times}{(1 - x_1 - x_2 - x_3) \times} \rightarrow$$

$$\rightarrow \frac{\times (\beta + x_1)(1 + S - 2x_1 - x_2 + 0,5x_4)}{\times (\alpha - 4x_1 - 2x_2 - x_3 + x_4)^4}$$

$$K_2 P = \frac{(\delta + 2x_1 + 2x_2 + x_3 - x_4)^2 \times}{(1 - x_1 - x_2 - x_3) \times} \rightarrow$$

$$\rightarrow \frac{\times (1 + S - 2x_1 - x_2 + 0,5x_4)}{\times (\alpha - 4x_1 - 2x_2 - x_3 + x_4)^2}$$

$$K_3 = \frac{(\gamma + x_3)(\sigma + 2x_1 + 2x_2 +}{(1 - x_1 - x_2 - x_3) \times} \rightarrow$$

$$\rightarrow \frac{+ x_3 - x_4)}{\times (\alpha - 4x_1 - 2x_2 - x_3 + x_4)} \qquad (11)$$

$$K_4 P^{1/2} = \frac{(\alpha - 4x_1 - 2x_2 -}{(\delta + 2x_1 + 2x_2 + x_3 - x_4) \times} \rightarrow$$

$$\rightarrow \frac{- x_3 + x_4) \, 0,5x_4}{\times (1 + S - 2x_1 - x_2 + 0,5x_4)}$$

Analysis of values for coefficients K_1–K_4 in the temperature range of 1000–1300 °K indicates that in special cases (which may have a bearing on the basic variants of technological mode), the system of equations (11) can be considerably simplified. Thus, if coal formation (I) or methane formation (II) does not occur and $N_{CH}^0 = 0$, the system of equations is transformed into a system of 3 equations with 3 unknowns. If, however, conditions (I) and (II) are both met, thermodynamic equilibrium of the reaction mixture is described by a system of two equations with two unknowns (III).

Case I corresponds to the following system of equations:

$$K_1 P^2 = \frac{(\delta + 2x_1 + x_3 - x_4)^2 \times}{(1 - x_1 - x_3) \times} \rightarrow$$

$$\rightarrow \frac{\times (1 + S - 2x_1 + 0,5x_4)^2 (\beta + x_1)}{\times (\alpha - 4x_1 - x_3 + x_4)^4}$$

$$K_3 = \frac{(\delta + x_3)(\delta + 2x_1 + }{(1 - x_1 - x_3) \times} \rightarrow$$

$$\rightarrow \frac{+ x_3 - x_4)}{\times (\alpha - 4x_1 - x_3 + x_4)} \qquad (12)$$

$$K_4^2 P^{-1} = \frac{0,5x_4 (\alpha - 4x_1 - }{(\delta + 2x_1 - x_3 + x_4)^2 \times} \rightarrow$$

$$\rightarrow \frac{- x_3 + x_4)^2}{\times (1 + S - 2x_1 + 0,5x_4)},$$

where N_i is found from (9), in which we must assume that $\beta = 0$ and $x_1 = 0$.

Case II corresponds to the following system of equations:

$$K_2 P = \frac{(\delta + 2x_2 + x_3 - x_4)^2 \times}{(1 - x_1 - x_3) \times} \rightarrow$$

$$\rightarrow \frac{\times (1 + S - x_2 + 0,5x_4)}{\times (\alpha - 2x_2 - x_3 + x_4)^2}$$

$$K_3 = \frac{(\gamma + x_3)(\delta + 2x_2 + x_3 - x_4)}{(1 - x_1 - x_3)(\alpha - 2x_2 - x_3 + x_4)} \qquad (13)$$

$$K_4^2 P^{-1} = \frac{0,5x_4 (\alpha - 2x_2 - }{(\delta + 2x_2 + x_3 - x_4) \times} \rightarrow$$

$$\rightarrow \frac{- x_3 + x_4)^2}{\times (1 + S - x_2 + 0,5x_4)},$$

where N_i is found from (9), in which it must be assumed that $\beta = 0$ and $x_2 = 0$.

Case III corresponds to the following system of equations:

$$K_3 = \frac{(\gamma + x_3)(\delta + x_3 - x_4)}{(1 - x_3)(\alpha - x_3 + x_4)}$$

$$K_4^2 P^{-1} = \frac{(\alpha - x_3 + x_4)^2 \, 0,5x_4}{(\delta + x_3 - x_4)^2 (1 + S + 0,5x_4)}, \qquad (14)$$

where N_i is found from (9), in which it must be assumed that $x_1 = 0$, $x_2 = 0$, $\beta = 0$.

To determine the cases (with which set of P, T, N_i) one can use one of the systems (12)-(14) instead of (11), it is sufficient to first solve the following system of equations:

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$$K_1 P^2 = \frac{(\delta + 2x_1 + 2x_2 + x_3)^2 \times}{(1 - x_1 - x_2 - x_3) \times} \rightarrow$$

$$\rightarrow \frac{\times (\beta + x_1)(1 + S - 2x_1 - x_2)^2}{\times (\alpha - 4x_1 - 2x_2 - x_3)^4}$$

$$K_2 P = \frac{(\delta + 2x_1 + 2x_2 + x_3)^2 \times}{(1 - x_1 - x_2 - x_3) \times} \rightarrow$$

$$\rightarrow \frac{\times (1 + S - 2x_1 - x_2)}{\times (\alpha - 4x_1 - 2x_2 - x_3)^2} \qquad (15)$$

$$K_3 \frac{(\gamma + x_3)(\delta + 2x_1 + 2x_2 + x_3)}{(1 - x_1 - x_2 - x_3)(\alpha - 4x_1 - 2x_2 - x)_3},$$

which is obtained on the assumption that $x_4 = 0$. The validity of this approach is confirmed by the fact that K_4 can be disregarded within the range of temperatures of interest to us.

It is possible to derive working equations for the tested gas mixture with consideration of extraction of oxygen from it with use of a coefficient that determines the extent to which oxygen passes from the cathode to anode space of the electrolyzer.

CENTRAL HEMODYNAMICS OF MONKEYS IN POSTOPERATIVE PERIOD AS RELATED TO HANDLING PRIOR TO SURGICAL INTERVENTION

[Article by R. T. Kazakova, V. P. Krotov and I. O. Giryayeva]

[English abstract from source] The pumping and contractile cardiac function of monkeys was examined at different time intervals after electrode and transducer implantation. The study was carried out using 26 rhesus monkeys under ketalar anesthesia. The effect of this surgical intervention on intracardiac hemodynamics depended on the initial health state of the animals. Prior to operation the pumping function declined due to diminished motor activity of the animals. It remained decreased to a greater extent 10-15 days after operation. When normal motor activity was allowed even for a short time before surgical implantation, this was sufficient for normalization of the cardiovascular function. In view of these observations, we should be very cautious to expose monkeys to diminished motor activity for long periods of time.

[Text] The effect of the acute period of adaptation to weightlessness was studied on monkeys flown aboard Cosmos-1514 and Cosmos-1667 biosatellites. The animals were first trained to perform several programs of operator activity, which required a long stay in a primatological chair. We then performed several successive operations to implant transducers and electrodes. All of the above factors could affect the circulatory system and system of its regulation and, consequently, the nature of their function in weightlessness.

In this regard, it was deemed important to assess the effect of surgical interventions and animals' living conditions during the training period on pumping and contractile functions of the myocardium of the left ventricle (LV).

Methods

The stueis were conducted using the echocardiography method (1) on 26 Macaca rhesus monkeys 2.5-3.5 years of age with average weight of 4.3 kg. Three groups of animals were tested under ketalar anesthesia (5 mg/kg weight). The

1st group of animals were kept in a cage (6 animals) before surgery; the 2d group was kept in primatological chairs (12 monkeys) around the clock for 1.5-2 months; the 3d group was also kept in the charis, and allowed into the cage at least once or twice a week for 1 day (8 animals).

LV echocardiograms were recorded in the M mode from the aorta to the apex along the long axis of the heart using a UZKAR-3 echocardiograph (2.7 MHz transducer). The transducer was placed along the left edge of the sternum at the level of the 3d-4th intercostal space. Concurrently, we recorded the electrocardiogram (ECG). Measurements were taken on the level of the mitral valve chordae or on the level of visualization of two cusps at the site of intrinsic motion of the anterior wall and septum. The LV chambers in systole (D_s) and diastole (D_d) were measured from the echocardiogram. The systolic size of the chamber (smallest intraventricular dimension) was measured according to maximum approximation of structures of the posterior wall and septum [2]. Diastolic size of the LV chamber was measured on the apical line of the R wave on the ECG. On the basis of the obtained data, we calculated LV volume: $V = [7/(2.4+D)]D^3$ (D is size of LV), end systolic (ESV) and end diastolic (EDV) volumes of the LV. We calculated stroke volume: SV = EDV − ESV, ejection fraction: EF = SV/EDV, circulation volume: CV = SV·HR (HR is heart rate) and degree of shortening of anteroposterior size of LV in systolic period: ΔS (%) = $[D_d - D_s)/D_d]$·100. In addition we determined the diameter of the aorta and size of the left atrium, as well as thickness of the interventricular septum and posterior wall of the left ventricle.

Echocardiography was performed at the same time of day with the animals in supine position. Baseline tests were made on intact animals before surgical intervention. For this purpose, a plastic hood was put on the animal's head, sensors were implanted over the carotid artery to measure arterial pressure and blood flow and, in addition, electrocardiographic, rheographic and electromyographic electrodes. Subsequent echocardiography was performed at different times following the final stage of surgery: on the 3, 10th and 20th days for animals in the 1st group, 10th-15th and 20th-25th days for the 2d group, 3d and 10th days for the 3d group. It must be noted that not all of the animals in the 2d and 3d groups were tested at the indicated times.

Results and Discussion

One day before the first stage of the operation, the parameters of LV pumping function were appreciably lower in the 2d group of monkeys than in the 3d. Since the monkeys in these groups were of the same age and weight [3], these changes can apparently be attributed to upkeep conditions before surgery.

Evidently, even a brief (1-2 days per week) stay in the cage, which allowed for customary motor activity, was sufficient to maintain normal levels of the tested parameters. The data obtained on cardiac pumping function in the 1st and 3d groups of monkeys before the operation conform well to the results of studies conducted on anesthetized healthy animals under ordinary upkeep conditions, using the Fick method [4] and echocardiography [2].

The role played by the baseline functional state with respect to providing adequate cardiac function is subsequently evident with respect to dynamics of normalization of parameters in the postoperative period.

Table 1. Central hemodynamic parameters at different postoperative stages in 1st group of monkeys (M±m)

Parameter	Pre-op.	Postoperative day		
		3-u	10-c	20-c
HR/min	139,5±5	135±8	140±5	137±8
SV, ml	9,3±0,4	9,2±0,4	9,2±0,4	9,1±0,5
SI, ml/mg [sic]	1,84±0,13	1,9±0,1	1,9±0,1	1,9±0,3
CV, ml/min	1293±84	1261±131	1292±94	1269±149
CI, ml/(min•kg)	262±22	262±33	268±28	262±39
EDV, ml	14,6±0,5	15±0,3	14,4±0,4	14,4±0
ESV, ml	5,4±0,3	5,3±0,2	5,2±0,3	5,2±0,3
EF, %	63±2	64±2	64±2	63±2
ΔS, %	32±1	33±1	33±1	32±1
Animals' wt., kg	5,0±0,2	4,9±0,4	4,9±0,2	4,9±0,2

Note: Here and in Tables 2 and 3: CI) cardiac index, SI) stroke index

The parameters of intracardiac hemodynamics did not differ from baseline values in the 1st group of monkeys as early as the 3d postoperative day (Table 1). At the same time, SV dropped by 24±5.5% (p<0.05) and SI by 22% in the 2d group, on the 10th–15th day after the final stage of surgery. In spite of the rise in HR (by 18%), CV was also diminished (by 10%). The reliable decline of DB was due to moderate decrease in both venus return (EDV decreased by 12.4%) and parameters of contractility of the LV myocardium (EF by 12% and ΔS by 14%). On the 20th–25th days, the main parameters reverted to the baseline level or were even somewhat above it.

Table 2.
Central hemodynamics of 2d group of monkeys before and after the operation (M±m)

Parameter	Pre-op.	10-15 d after surgery
HR/min	144±13	170±16
SV, ml	6,6±0,8	5,1±0,7*
SI, ml/kg	1,73±0,25	1,35±0,3
CV, ml/min	936±65	846±92
CI, ml(min•kg)	238±13	225±40
EDV, ml	11,2±0,6	9,8±0,9
ESV, ml	4,6±0,2	4,7±0,9
EF, %	59±2	52±6
ΔS, %	29±1	25±3
Animals' wt., kg	4±0,4	3,9±0,3

Note: Only 4 of the 12 monkeys in the 2d group were tested on the 10th–15th day. Here and in Table 3: asterisk indicates P<0.05, as compared to preoperative data.

Analysis of the results of testing the 3d group of animals revealed that only HR and CV changed on the 3d and 10th postoperative days, whereas parameters of cardiac contractile function did not differ from baseline values (Table 3). The size of the left atrium, as well as diameter of the aorta, thickness of the interventricular septum and posterior LV wall did not change in any of the groups of monkeys.

Thus, the obtained data indicate that the effect of surgical intervention on intracardiac hemodynamics is determined by the baseline functional state of the animal. In the case of long-term and continuous restriction of movement, LV myocardial function remains diminished 10–15 days after surgery, even in comparison to the already low levels in the preoperative period. Evidently, one can predict the dynamics of postoperative recovery of pumping and contractile function of the

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Table 3. Parameters of central hemodynamics of monkeys in 3d group at different postoperative stages (M±m)

Parameter	Pre-op.	3d Post-op. day	Pre-op.	10th Post-op. day
HR/min	126±3,7	149±3,7*	128±3,7	157±7,5
SV, mℓ	8,7±0,4	8,7±0,4	8,3±0,4	8,6±0,2
SI, mℓ/kg	2,22±0,13	2,09±0,09	2,01±0,25	1,96±0,16
CV, mℓ/min	1094±55,4	1289±54*	1068±77	1359±84
CI, mℓ/(min·kg)	277±17,6	310±16,5	260±28,8	304±32,5
EDV, mℓ	13,9±0,5	13,9±0,5	13,7±0,4	14,1±0,3
ESV, mℓ	5,2±0,3	5,2±0,3	5,4±0,7	5,4±0,4
EF, %	62±2	62±2	60±3	61±2
ΔS, %	31±1,4	31±1,4	30±2	31±1,3
Animals' wt., kg	3,9±0,1	4,2±0,2	4,2±0,3	4,5±0,4

Note: On the 3d day 7 out of the 8 monkeys in the 3d group were tested and on the 10th day, 5 animals.

heart of monkeys. Brief return to the monkeys' customary motor activity was sufficient to normalize the function of the circulatory system and its adequate response to surgical intervention. Considering the foregoing, it is necessary to allow monkeys to spend a day in the cage once or twice a week both before and after surgical intervention when they are to be kept in primatological chairs. In addition, it is expedient to test simian hemodynamics at least 2 weeks after the final stage of surgery. This can be considered sufficient time for normalization of parameters of LV pumping function.

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PRESSURE AND VOLUME PULSATION WITH CHANGE IN 'SPARE ROOM' IN INTRACRANIAL CAVITY

[Article by L. G. Simonov and A. S. Saribekyan]

[English abstract from source] Changes in the amplitude and phase characteristics of pulse variations of volumes and pressures in response to an increase in the intracranial pressure are discussed. The study of 60 neurosurgical patients has shown that as the intracranial (subdural) pressure grows the amplitude of pulse variations of subdural pressure increases to 30 mm Hg and then decreases, the phase characteristics of the pulse waves changing accordingly. The changes in the amplitudes of pulse variations produced by mechanical displacement of the walls of cerebral lateral ventricles measures with the aid of the noninvasive ultrasonic method suggest than an increase in the CSF pressure above 200 mm H_2O makes the intracranial cavity too "tight," which depletes the reserve spaces of the cerebrospinal system. If the above changes develop consistently, then it can be assumed that each of the pressure ranges isolated can be characterized by amplitude-phase parameters of pulse waves that form a specific pattern. Taking into consideration the potentials of noninvasive measurements of amplitude-phase characteristics of the intracranial pulse wave by means of ultrasonic echolocation, it deems possible to develop noninvasive techniques for measuring compensatory abilities of the cerebrospinal system.

[Text] Investigation of the role of "spare room" in the cerebrospinal system and analysis of mechanisms of regulation of intracranial volumes with different forms of redistribution of fluids are important to evaluation of the severity of cerebral disturbances in the presence of hypertensive states.

The rigidity of bones and elasticity of the dura mater limit the possibility of increment of fluid volumes in the cerebrospinal system, and they play the leading role in formation of intracranial (intracerebral, cerebrospinal) pressure.

The anatomical distinctions of the cerebral and spinal parts of the system of blood and spinal fluid circulation make it possible to compensate, within a certain range, the possible changes in fluids by altering the volume relationships between blood and spinal fluid.

Baseline pressure levels in interacting hydrodynamic systems (arterial, venous and cerebrospinal fluid) determine the extent and degree of redistribution of fluid volumes in the cranial cavity.

Our objective here was to assess the relevance of parameters of pulsed fluctuations of volume and pressure with change in intracranial pressure.

Methods

The studies were conducted with use of both invasiv and noninvasive methods. Invasive methods were used to measure intracerebral (P_c) [4], intracranial subdural (P_s) and spinal fluid (P_f) pressures [3] and local cerebral blood flow [2] in 60 neurosurgical patients with various brain lesions. The existing experimental theoretical conception [12, 14] of "spare room" in the cerebrospinal system was verified in a study on the carcass of a Macaca rhesus monkey (in collaboration with V. P. Krotov). Parameters of intracranial spinal fluid dynamics were determined in 30 patients by means of ultrasound echolocation [8, 9]. Of this number, 9 patients were submitted to examination (with Ye. Ye. Razumovskiy) of pulsed damping of ultrasound [6], a parameter that reflects the degree of mechanical displacement of the walls of the lateral ventricle of the brain during pulsed increments of blood volume in the cranial cavity. Methods of variation statistics were used to process the data.

Results and Discussion

The study of the monkey carcass yielded intracranial pressure (P) determined subdurally (P_s) as a function of volume of saline (V) injected in different amounts into the ventricle ($\Delta V_i = 0.3$ ml). P_s is a nonlinear function of ventricular system volume, i.e., a unit of volume increment (ΔV) leads to different pressure increments (ΔP) when there are different baseline volume (V) levels. On the whole, it characterizes a decrease in spare room of the cerebrospinal system with rise in pressure in the cranial cavity as V of the ventricular system rises. The insignificant slope of this function at low values of V and low P characterizes the presence of spare room in the cerebrospinal system.

Ye. Shevchikovskiy et al. [12] demonstrated that when analyzing the P-V function it is necessary to use the expression that characterizes the modulus of elasticity $\left(E = \frac{dP}{dV} \right)$. Two areas are visible on the E = f(P) curve, each of which can be approximated with a line. The first segment of the obtained curve is virutally parallel to the P axis, while the second has a distinct slope (Figure 1). The range of "optimum" pressure [12] is characterized by the first segment of the E = f(P) curve, on which E does not grow, or else there is insignificant growth. From the curve, one can determine the maximum "optimum" pressure beyond which there is depletion of spare room of the cerebrospinal system. In this experiment, maximum optimum pressure was 216 mm water. In the invasive studies of spare room of the cerebrospinal system of patients
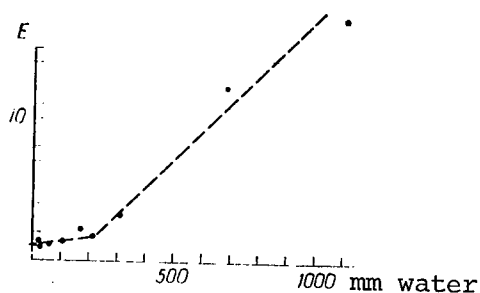
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Figure 1.
Elasticity E as a function of
pressure Ps in cerebrospinal sys-
tem. Explained in the text

with brain lesions, maximum value of
optimum pressure reached 160 mm water
[12]. As we know, the top of the normal
range is generally considered to be 200 mm
water for spinal fluid pressure [11].

Ultrasonic echolocation revealed that,
with controlled change in cerebrospinal
pressure, pulsed damping of ultrasound
(α_p) is a function of pressure. It has
an extreme value α_p^{max}, which differs re-
liably at a pressure of P = 220±18 mm
water (Figure 2a) from its values at 100
and 300 mm water (p<0.05). Evidently,
this means that there is "spare room"
up to the level of α_p^{max} the volume of
which diminishes with rise in spinal
fluid pressure (see Table).

Characteristics of volumes and pressures of elements in blood and
cerebrospinal fluid system

Material studied	V, cm^3	Pressure, mm water (mm Hg)	"Spare room"	Reference
Brain tissue: cerebral	1000	200—300 (22—26)	none	|7|
Spinal fluid system: spinal	100	—	none	|13|
cerebral	150	70—200 (5—16)	none	|13|
spinal	150	70—200 (5—16)	present	|13|
Venous system (intra-cranial)	100—150	to 100 (to 8)	present	|4|
Arterial system	50—100	400—1200 (30—90)	none	|3|

The mechanism of elevation of intracranial pressure varies. There may be
worsening of efflux of blood in the jugular veins (for example, in the
Queckenstedt test) or elevation of central venous pressure (Valsalva test)
and, furthermore, elevation of spinal fluid pressure (Stookey test) by means
of infusing an additional volume into the cerebrospinal system or as a result
of change in correlation between production and absorption of spinal fluid.

In our studies, the rise in α_p to α_p^{max} apparently occurs because of decline
of the gradient (ΔP) between spinal fluid (P_f) and intracerebral (P_c) pressure.
We know from the literature of the significance of intracerebral tissular
pressure, which constitutes (according to several authors) 200–300 mm water
[5, 10]. For this reason, the possibility cannot be ruled out that α_p reaches
α_p^{max} at spinal fluid pressure of P_f = 220±18 mm water which equals intra-
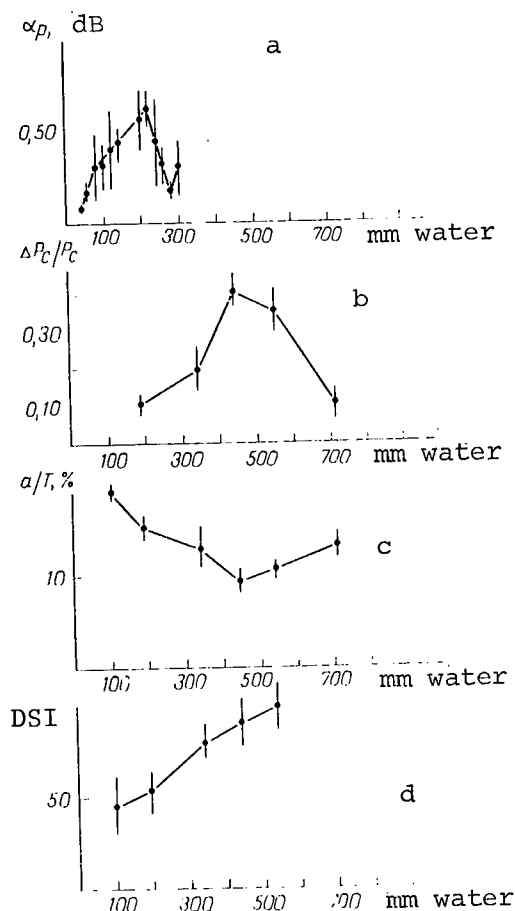cerebral tissue pressure.

Figure 2.
Characteristics of pulsed fluctuations of volume and pressure at different levels of intracranial pressure
  a) amplitude (dB) of mechanical displacement of lateral ventricle walls during pulsed influx of blood to the brain obtained by ultrasound method at different levels of cerebrospinal fluid pressure
  b) relative changes in amplitude of pulsed fluctuations of pressure
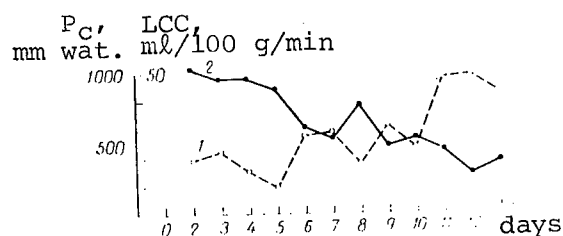 c) changes in time of anacrotic phase (%)
  d) DSI--diastolic index

Figure 3.
Changes in local cerebral circulation (LCC) with change in intracerebral pressure (ICP) in neurosurgical patients in the postoperative. 0--operation
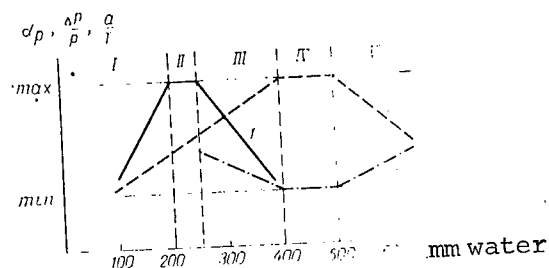
Figure 4.
Range of intracranial pressures with their inherent patterns
  I-V) range of pressures
   1) α_p
   2) $\Delta P/p$
   3) a/T

Brain tissue has a stroma and this is apparently the cause of the gradient between intracerebral tissue pressure and pressures in the blood and spinal fluid systems of the brain. However, when intracranial pressure rises and there is less spare room, of course ΔP drops.

The decrease in spare room and increased "crowdedness" [12] cause the coefficient of transmission of arterial pulse to the brain to come close to 1, which is apparently what leads to increase of α_p to α_p^{max}.

Upon further rise of P_f there is also rise of intracranial P_c, decline of ΔP and limited possibility of pulsed displacement of ventricular walls, for which reason α_P begins to drop (at 280 mm water, α_P already differs reliably from α_P^{max}, $p<0.05$). This is apparently indicative of exhaustion of compensatory mechanisms (spare room) of the cerebrospinal system (spinal fluid and different collectors of venous system) which are instrumental in pulsed transfer of spinal fluid between the cerebral and spinal regions. In this case, there should still be some "spare room" in the intracerebral venous system. This is confirmed by the fact that there can be an increase in pulsed fluctuations of P_s of the brain with elevation of overall intracranial pressure to more than 300 mm water (Figure 2b). Pressure in the venous system (normally) does not exceed 100 mm water (see Table). The rather large volume of the intracranial venous system, low pressure in it and capacity of its intracranial part make the predominant contribution to compensatory capacities with changes in intracranial fluid volume relations.

Figure 2b-d illustrates the parameters of the pulsed wave of subdural pressure (ΔP_s) with rise of P_s. As can be seen in Figure 2b, $\Delta P_s/P_s$ increases up to $P_s = 30$ mm Hg (408 mm water), which distinguishes it reliably from the values at 300 and 700 mm water ($P<0.05$), after which it begins to drop. The a/T ratio (a--anacrotic phase, T--period) as a function of P_s is analogous (with the opposite sign), and a/T differs reliably from the minimum at 340 and 700 mm water ($p<0.05$, see Figure 2c), while the diastolic index (DSI), which determines the state of blood efflux from the cranial cavity, retains a tendency toward change in the same direction (see Figure 2d): there is reliable change in DSI at pressure above 200 mm water ($p<0.05$).

Thus, occurrence of an extreme-maximum as a function of $\Delta P_s/P_s = f(P_s)$ and of a minimum as a function of a/T $= f(P_s)$ is apparently evidence of diminished spare room in the venous system, depletion of which is manifested by decline of $\Delta P_s/P_s$ ratio with further rise of P_s and increase in anacrotic phase a/T.

It is thus apparent that the decline of $\Delta P_s/P_s$ with rise of P_s could be due to (a sign of) worsening of perfusion pressure, i.e., pulsed delivery of blood to the brain. Then the changes in a/T could be indicative of decline of velocity characteristics of arterial blood flowing in a given hemisphere, while the DSI as a direct function of P_s could be a sign of consistent worsening, against such a background, of conditions for venous efflux from the cranial cavity via the venous system. Evidently, this is the cause of the negative correlation between local cerebral circulation and intracerebral pressure (Figure 3a), which is very evident in the presence of intracranial hypertension [5].

Thus, as shown by the results of our studies, the amplitude and phase characteristics of pulsed flucutations of pressure or volume depend on the intracranial pressure, and for this reason they may be of diagnostic value.

Our conception, which characterizes the mechanism of depletion of "spare room" in the cerebrospinal cavity with rise of intracranial pressure, is based on the data we obtained concerning the extreme nature of amplitudes of pulse curves as a function of intracranial pressure, and it is hypothetical to some

extent, since it reflects the hypothesis expounded by A. I. Arutyunov and E. B. Sirovskiy [1] concerning the presence, significance and role of intracerebral stroma.

Extreme factors, changes in direction of action of gravity forces to which man may be exposed while working under special conditions, as well as states related to various brain lesions, alter intracranial volumes of fluids and could lead to depletion of the "spare room" in interacting hydrodynamic systems.

We believe that the results of analysis of the distinctions of amplitude and phase characteristics of pulsed fluctuations contain important information, which could be used not only in invasive, but noninvasive tests.

Having determined the range of intracranial (intracerebral, subdural) pressure that is critical to the hemodymaic arterial pressure (P_{cr}; 400-500 mm water), which is not in contradiction to data in the literature [17, 19] indicating a drop of perfusion pressure and worsening of blood flow parameters at pressure above 30 mm Hg, we have actually demonstrated the range in which there is spare room (range of values corresponding to the left arm of the $\Delta P/P_s = f(P_s)$ curve (see Figure 2b). It is necessary to note here that low values for hemodynamic characteristics may also occur at below P_{cr}, but this cannot, of course, be related to the intracranial pressure factor.

In our opinion, the passage through a maximum for $\alpha_p = f(P)$ with rise of spinal fluid pressure is a rather distinct criterion of pressures in the cerebrospinal system.

Comparative analysis of the dynamics of parameters α_p, $\Delta P/P$ and a/T during rise of intracranial pressure revealed that there are several patterns. Figure 4 shows the ranges of pressure with their inherent patterns: range I--α_p, $\Delta P/P$ rise, a/T drops; range II--further rise of α_p and $\Delta P/P$ with the former reaching a maximum; range III, further rise of $\Delta P/P$, decline of a/T and α_p; range IV--maximum $\Delta P/P$, further decline of α_p and reaching maximum and minimum values for $\Delta P/P$ and a/T; range V--further decline of α_p and other tested parameters.

Provided that the above changes are a pattern, it can be assumed that specific types of changes in dynamics of intracranial blood and spinal fluid circulation correspond to each of the distinguished ranges, and these changes are manifested by changes in α_p, $\Delta P/P$ and a/T, forming a concrete pattern that is typical of pressure build-up over a specific range.

Of interest is the fact that the diversity of dynamics of the above parameters is the most marked in ranges II, III and IV, from 200 to 450 mm water, i.e., in the range limited by the top of the normal range of intracranial pressure and critical intracranial hypertension, in which there is, according to the literature, reduction of cerebral blood flow due to worsening of conditions for arterial influx of blood to the brain. The consistent alternation of patterns, which characterizes the sequence of spinal fluid and blood system processes in ranges II, III and IV could be a reflection of the dynamics of compensatory processes due to the state of the spare room in the brain, ranging from appearance of early compensatory reactions to their complete depletion.

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At the present time, it is difficult to unequivocally describe the physiological essence of each range (or level) of compensation or to define the relevance of some concrete element of spare room to formation of a given level of compensation. However, considering the known capacities of the different elements that interact in the intracranial hydrodynamic systems, it can be assumed that the compensatory responses that occur with pressure changes in range II are attributable primarily to the distinctions of the spinal fluid system, whereas in ranges III and IV they are attributable to the venous system.

We could expound the hypothesis that there are two phases in the venous level of compensation that are attributable to the responses of the intracranial and extracranial venous systems.

In view of the available opportunity to make noninvasive determination of α_p, a/T, DSI and other relevant parameters by means of ultrasonic echolocation of the brain, in determining and validating the appropriate criteria for assessing the intracranial pressure we shall be able to turn to noninvasive determination of compensatory capacity of the "spare room" in the cerebrospinal system.

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CLINICAL STUDIES

COMPARATIVE STUDY OF CENTRAL HEMODYNAMICS, MYOCARDIAL CONTRACTILITY AND LEFT VENTRICULAR WALL TENSION IN ATHLETES AND PATIENTS

[Article by B. A. Khodos and V. L. Gabinskiy]

[English abstract from source] The purpose of the study was to extent our knowledge about the "athletic" heart and improve diagnosis of latent manifestations of cardiac insufficiency. Echocardiography was used to examine central hemodynamics, myocardial contractility and left-ventricle wall tension in athletes and patients with ischemic heart disease (IHD) and arterial hypertension at rest and after exercise tests. The study of time-course variations of these parameters revealed different patterns of initial dilation and development of further dilation and hypertrophy in athletes and patients. The most sensitive index of contractility was meridional and circular tension of the left-ventricle wall which was the lowest in athletes and the highest in IHD patients.

[Text] The dramatic increase in volume of training loads in recent times has made it necessary to prusue more comprehensive studies of the cardiovascular responses of athletes in order to prevent myocardial dystrophy. It is expedient to use echocardiography to assess the morphological and functional distinctions of the heart of athletes. This technique yields substantial additional data for the study of the nature of adaptive respones of the circulatory system to heavy physical loads [2, 10], and it provides for high reproducibility of the dynamics of changes in size and functions of the left ventricle [14]. There have been few studies in the field of sports medicine with use of echocardiography, and their results are contradictory. According to some researchers, dilatation and hypertrophy demonstrable in athletes do not reach levels inherent in pathological states [2, 3]; according to other data, they are analogous or more marked than in patients whose heart is subject to pressure and volume load [18]. Accordingly, researchers have used different approaches to the adquacy or "physiological nature" of changes in the athletic heart.

There have been few studies of such important parameters of myocardial contractility as end systolic meridional and circular tension of walls.

A comparative study of adaptation of the cardiovascular system of athletes and patients to physical loads will expand our knowledge about the morphological and functional distinctions of the athletic heart, means of formation of dilatation and hypertrophy in athletes and patients, and would improve the detection of latent manifestations of cardiac insufficiency.

Methods

We had under observation 15 highly qualified athletes (sports masters, international class sports masters) on the SKIF [Athletic Club of the Institute of Physical Culture] handball team (Krasnodar), which had competed in the top league in a USSR championship, 20 patients with ischemic heart disease (IHD) under hospital care in a regional hospital and 20 patients with arterial hypertension (AH) who were picked up in a screening of the regional public. Neither group of patients presented circulatory insufficiency; the IHD patients suffered from tension angina pectoris of functional classes I and II without cicatricial changes. The two control groups consisted of healthy men who were not involved in sports. The athletes and men in the 1st control group ranged in age from 20 to 30 years; the patients and 2d control group were 40–49 years old. They were examined in the morning, at least 3 h after taking food.

Echocardiography was performed in the M mode using a UZ-KAR-3 echocardiograph, with tracing rate of 50 mm/s. Considering the recommendations of WHO [17], measurements were taken on the level of the mitral valve chordae upon obtaining a distinct image of both margins of the interventricular septum (IVS) and endocardium of the posterior wall (PW) of the left ventricle (LV). End diastolic dimensions were measured at the start of the Q (R) wave on the ECG and end systolic size, at the moment of shortest distance between the IVS and LV PW. We calculated the resting end diastolic (EDV) and systolic (ESV) volumes using the Teichholz formula, stroke (SV) and minute (MV) volumes, thickness and systolic thickening of LV PW (TPW and STPW, respectively), IVS (TIVS and STIVS), as well as weight of the myocardium (MM) using the formula proposed by the staff of the All-Union Cardiological Research Center, USSR Academy of Medical Sciences [9], ejection fraction (EF), fraction of LV chamber shortening (ΔD), rate of shortening of circular myocardial fibers (V_{CF}) and rate of relaxation of LV PW (V_D).

We measured the end systolic meridional wall tension (σ_m) using the formula of Reichek [16] and circular tension (σ_c) by the Quinones formula [15].

Considering the difficulties involved in obtaining a good echocardiogram at peak physical load, as well as the fact that the hemodynamic changes in the 1st min after stopping exercise correspond to peak levels and revert to the baseline only by the 6th min of rest [11], we recorded the postexercise parameters--EDV, ESV, SV, MV, EF, ΔD, V_{CF} and V_D--by the end of the 1st min after cycle ergometry. We used an exercise load that increased continuously in steps on a Tuntury (Finland) cycle ergometer, and its magnitude constituted 50 W at first for individuals 20-30 years of, increasing by 50 W at each step. They exercised at each level for 4 min. For subjects 40-49 years of age, duration of each step was analogous, while the starting load and increment at each step constituted 25 W. The test was stopped upon reaching submaximum HR (80-90% of maximum). Maximum HR was calculated using a previously submitted

formula [1, 7]. We measured BP [blood pressure] and recorded the ECG using Nehb's leads (Mingograph-34, Sweden) before cycle ergometry and at the end of each step of the load.

The material was submitted to statistical processing with use of Student's criterion. Arithmetic mean deviation was determined according to Peters using Moldenhauer's factor.

Results and Discussion

A reliable increase in EDV and ESV was observ-d at rest in athletes and IHD patients, and in AH cases there was increase in EDV, SV and MV (Table 1). TPW, STPW, TIVS, STIVS and MM were greater in athletes than the other subjects, there being predominant hypertrophy of the IVS (1.28 cm versus 1.20 LV PW). There was a reliable increase in TPW and MM in AH patients, as compared to the control group; however, thickness of all walls and MM were reliably lower than in athletes. We failed to demonstrate any appreciable differences in these parameters between IHD cases and the control group. The traditional contractility indexes failed to show differences in any of the groups. Against this background, it was particularly productive to calculate σ_c and σ_m (Figure 1). They were lowest in athletes, as compared to all groups (P<0.01), whereas they were reliably higher in both patient groups than in the control group of the same age (P<0.05).
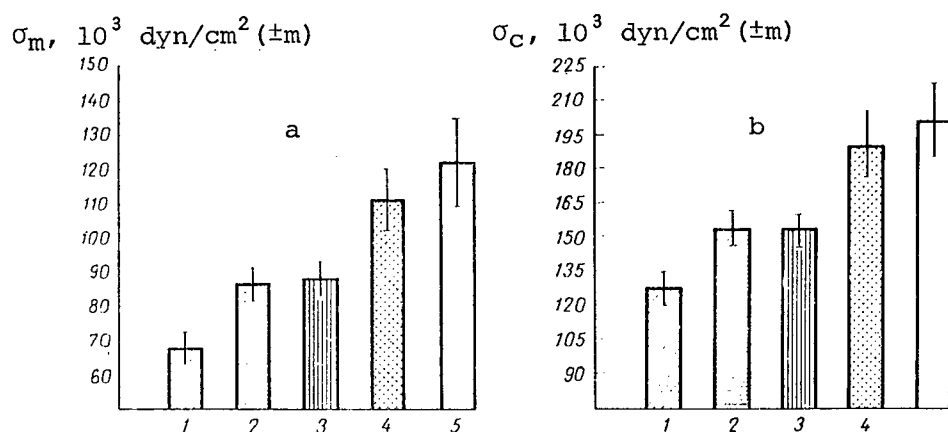
Figure 1.   End systolic meridional (a) and circular (b) tension of LV wall

1) athletes
2) control 40-49 years old
3) control 20-30 years old
4) AH patients
5) IHD patients

The differences between parameters were more significant after exercise (Table 2). EDV remained higher in athletes than control groups of the same age, but ESV showed relative decline and no longer differed appreciably; SV increased reliably. In IHD and AH patients, on the contrary, postexercise ESV exceed the control level, SV and EDV did not differ from control values. MV exceeded the control in athletes and AH cases. Athletes' parameters of contractility did not differ from those of the control group and AH patients (with the exception of V_D). In IHD patients, they became reliably lower than in all compared groups.

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Table 1. Baseline parameters of central hemodynamics and myocardial contractility in athletes, IDH and AH patients, and healthy subjects of the same age (M±m)

Group	EDV, ml	ESV, ml	SV, ml	MV, ℓ/min	T_{PW}, cm	T_{IVS}, cm	ST_{PW}, cm
Athletes	173,7 ±10,3*	80,4 ±7,9*	93,3 ±5,9	5,86 ±0,4	1,20 ±0 02*	1,28 ±0,03*	1,75 ±0,04*
Control, 40-49 years	138,4 ±8,6	66,4 ±6,4	72,0 ±6,2	5,08 ±0,4	0,90 ±0,02	0,91 ±0,03	1,37 ±0,07
Control, 20-39 years	138,6 ±6,0	59,0 ±3,4	79,6 ±3,7	6,26 ±0,3	0,90 ±0,02	0,89 ±0,02	1,38 ±0,02
AH patients	177,0 ±11,0*	77,5 ±6,6	99,5 ±7,4*	7,42 ±0,6*,**	1,07 ±0,03*,**	0,98 ±0,05**	1,36 ±0,03**
IHD patients	179,3 ±13,1*	97,1 ±7,6*	82,2 ±6,9	6,29 ±0,6	0,88 ±0,03**	0,91 ±0,04*	1,22 ±0,05**

Group	ST_{IVS}, cm	MM, g	EF, %	ΔD, units	V_{CF}, cir/s	V_D, cm/s	σ_m $\cdot 10^3$ dyn/cm^2	σ_c $\cdot 10^3$ dyn/cm^2
Athletes	1,87 ±0,04*	212,1 ±8,3*	0,55 ±0,02	29,1 ±1,6	1,02 ±0 05	9,5 ±0,6	67,6 ±4,3*	127,3 ±7,4*
Control, 40-49 years	1,48 ±0,08	139,0 ±5 8	0,52 ±0,03	27,5 ±2,1	1,05 ±0,10	8,0 ±0,3	85,9 ±4,4	152,9 ±5,8
Control, 20-30 years	1,36 ±0,06	134,8 ±3,9	0,58 ±0,01	30,6 ±1,0	1,18 ±0,05	8,6 ±0,2	87,4 ±4,5	153,6 ±6,4
AH patients	1,43 ±0,06**	174,7 ±8,7*,**	0,56 ±0,03	30,5 ±1,7	1,13 ±0,08	8,4 ±0,2	110,4 ±8,9*,**	191,2 ±13,0*,**
IHD patients	1,28 ±0,06**	138,7 ±8,6**	0,49 ±0,03	25,2 ±1,7	0,91 ±0,07	7,7 ±0,4	121,1 ±12,4*,**	201,7 ±17,6*,**

Here and in Table 2: *Reliable differences as compared to same age control. **Reliable differences as compared to athletes.

Table 2. Parameters of central hemodynamics and myocardial contractility in athletes, IHD and AH patients and healthy subjects of the same age following exercise (M±m)

| Group	EDV, ml	ESV, ml	SV, ml	MV, ℓ/min	EF, %	ΔD, units	V_{CF}, cir/s	V_D, cm/s
Athletes	199,6 ±11,6*	74,3 ±8,6	125,3 ±5,1*	14,67 ±0,7*	0,64 ±0,03	36,2 ±1,8	1,82 ±0,16	16,7 ±1,3
Control, 40-49 years	154,3 ±8,4	62,0 ±6,2	92,3 ±6,0	10,48 ±0,7	0,60 ±0,02	32,6 ±1,8	1,76 ±0,07	9,9 ±0,3
Control, 20-30 years	154,5 ±6,0	56,2 ±2,9	98,3 ±4,6	11,86 ±0,5	0,63 ±0,01	35,2 ±1,0	1,80 ±0,06	10,6 ±0,3
AH cases	183,4 ±11,9	82,4 ±7,4*	101,1 ±7,5**	13,00 ±0,8*	0,60 ±0,02	32,7 ±1,6	1,74 ±0,12	9,8 ±0 4**
IHD cases	194,4 ±19,8	104,0 ±15,0*	90,4 ±6,8**	9,42 ±0,8**	0,50 ±0,03*,**	26,1 ±1,9*,**	1,03 ±0,09*,**	8,0 ±0,5**

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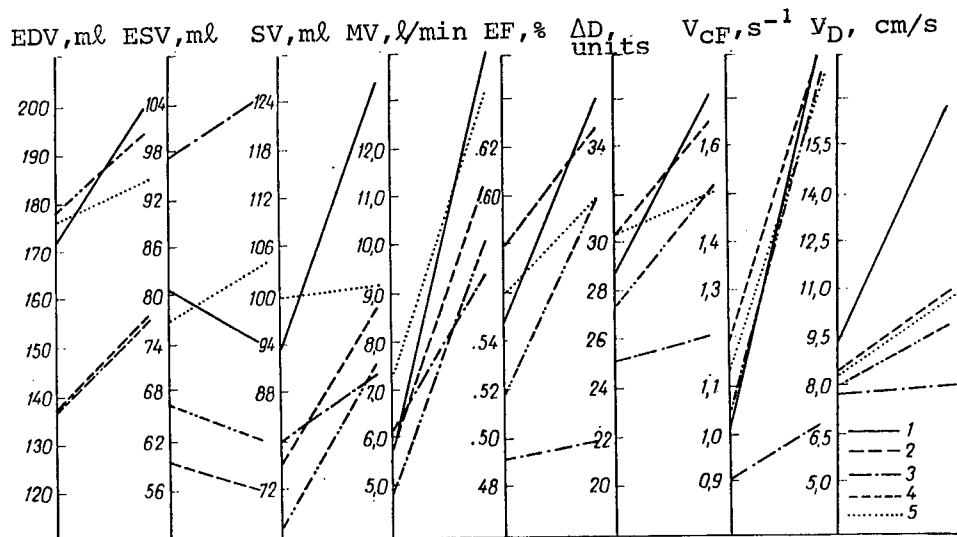
Figure 2. Dynamics of parameters of central hemodynamics and myocardial
contractility before and after exercise

1) athletes
2) control, 20-30 years

3) control, 40-49 years
4) IHD patients

5) AH patients

The changes in parameters after exercise within each group are also of some
interest (Figure 2). In athletes, there was reliable increase in SV, MV and
all parameters of contractility (P<0.01), there was increase in EDV and de-
cline of ESV, but these values did not reach a reliably significant level. In
IHD patients there was in crease in MV and in AH patients, in MV, V_{cF}, V_D.

Thus, in the baseline state, we demonstrated enlargement of the LV chamber in
athletes, AH and IHD patients, which coincides with the findings of other resear-
chers [2, 4, 5, 7-10, 12, 13, 18]. Initial presence of dilatation in athletes with ten-
dency toward decline of MV coincides with the conclusion of F. Z. Meyerson and
Z. V. Chashchina [7] that the heart of athletes functions more economically
and that they have a larger reserve used with exercise. This is confirmed by
the data we obtained following cycle ergometry, which demonstrated in this
group a reliable increment, not only of MV, but SV. The latter increase
was attributable to increase in EDV and decrease in ESV. In AH and IHD patients,
this pattern was not observed. The increase in SV, which was demonstrated in
AH patients at rest and not observed after exercise, is indicative of pre-
dominantly hyperkinetic type of circulation, which leaves no reserve for
physical exercise. In IHD patients, SV at rest and after cycle ergometry
did not differ from values for the control group of subjects. Postexercise
MV increment was obtained in both groups of patients only due to increase in
HR. Hypertrophy of the LV wall and MM were greater in athletes than AH cases,
which agrees with the data of Sugishita [18] and contradicts the statements of
other researchers [2, 3]. Apparently, it is not the absolute wall thickness
that is relevant here, but its relation to the size of the LV cavity and
arterial pressure. Csanady (1980) had previously reported the predominant
IVS hypertrophy that we found, in his study of canoe rowers, and Dickhuth
(1979) indicated the same in endurance runners. Conversely, in the AH patients,
the thickness of the LV exceeded that of the IVS. Apparently, this is

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attributable to the fact that the patients develop hypertrophy only of the LV, while athletes developed it in both ventricles. In IHD patients, thickness of the walls and MM did not differ from values for the control group.

After exercise, the athletes demonstrated a reliable increment of all parameters of contractility, which is indicative of predominant mobilization of inotropism according to F. Z. Meyerson [6] for hyperfunction. The postexercise decline of ESV in the same group was an indirect indication of this. In AH patients, we failed to demonstrate reliable differences in contractility, as compared to the control group, there was significant postexercise increment of V_{CF}, which was closely linked with HR and V_D. Evidently, in this group hyperfunction was implemented through both mobilization of the inotropic component and mechanism of Frank-Starling. In IHD patients, postexercise contractility parameters did not exceed baseline levels, but they became reliably lower than in the control. Hence, performance of hyperfunction in these patients occurs virtually without mobilization of the inotropic component, by means of predominant involvement of Frank-Starling mechanism. Thus, investigation of the dynamics of contractility confirms the fact that, in athletes, dilatation is of a different nature than in AH and particularly IHD patients, being the reserve that permits hyperfunction at a time of physical stress with mobilization of inotropic properties of the myocardium. Latent "inotropic insufficiency" was found in IHD patients, which did not permit intensification of myocardial contractility at the time of a physical load and consequently it led to latent cardiac insufficiency. Thus, in these patients, dilatation is a reflection of latent cardiac insufficiency.

The parameters, σ_c and σ_m, are important indicators of contractility, reflecting the correlation between systolic pressure, size of chamber and thickness of LV wall. Their baseline values showed reliable differences in contractility between athletes and patients, as compared to control groups, which indicates that they are more sensitive than the conventional parameter. Their further use will permit detection of latent inotropic insufficiency without use of physical stress tests. In addition, they indicate that, although hypertrophy is greater in athletes than patients whose heart is subject to a pressure load, the hypertrophy remains "physiological," since it develops as a mechanism aimed at lowering myocardial tension.

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SPECTRAL RENDITION OF VESTIBULAR NYSTAGMUS

[Article by A. V. Telezhnikov, V. G. Bazarov, V. L. Tsygankov, M. V. Kulikova and N. S. Mishchanchuk]

[Text] There is no information in published material dealing with vestibular nystagmus about use of spectral and correlation approaches to analysis of the electronystagmogram (ENG), which depicts a nonstationary random process related to two extremely important analyzer systems--vestibular and visual.

We submit here a spectral analysis of ENG obtained during the Barany rotation test at an angular velocity of 180°/s for 20 s.

For this analysis, we shall adhere to a model, in which it is assumed that the observed ENG during rotation and at the moment of culmination after rotation is the sum of a determined $f(t)$ and random u_t component [1].

Evaluation of spectral density power (SDP) or simply the spectrum of quantized determinate component is made by means of procedures that make use of Fourier's rapid transform (FRT). Such an approach to spectral analysis is effective in computing and yields acceptable results for a large class of signal processes. However, there are several basic limitations to the approach based on calculation of FRT. The most important is the limitation of frequency resolution, i.e., capacity to distinguish the spectral lines of two or more signals. The second limitation is attributable to weighted data processing in calculating the FRT. Weighing is manifested in the form of a "leak" in the frequency range, i.e., the energy of the major lobe of the spectral line "leaks" into the lateral lopes, which superimposes other signals present and distorts the spectral lines. The spectral lines of weak signals could be obscured by the lateral lobes of spectral lines of stronger signals. For this reason, methods of spectral analysis based on SDP are characterized by the fact that a number of compromise assumptions must be made in attempting to obtain statistically reliable spectral evaluations. This pertains to the duration of recording l, the length of which should be on the order of $l \geqslant \frac{1}{f_2 - f_1}$ where f_1 and f_2 are frequencies of spectral lines, for a rectangular window (choice of weighting function) and greater than $\frac{2}{f_2 - f_1}$ for windows that are not

rectangular [3]. A compromise in proper choice of window function minimizes leakage into the lateral lobes; however, this could lead to reduction of resolution. These two limitations for approaches based on FRT are particularly manifest when analyzing short tracings of data. It is expressly with such tracings that one has to deal in practice most of all, since the duration of the response to the Barany rotation test is 50-70 s.

Thus, the windows must have the following properties:

1) Width of the major lobe of the window's frequency response containing as large a part of total energy as possible must be small.

2) The energy in the lateral lobes of the frequency response should be as low as possible.

Having analyzed several types of windows approximating the above-mentioned responses, it can be concluded that the Kaiser window is the most suitable to our purpose. The latter is optimal because it constitutes a sequence of finite length with minimum spectral energy beyond the limits of the specified frequency, which is the most informative spectral assessment when analyzing periodograms.
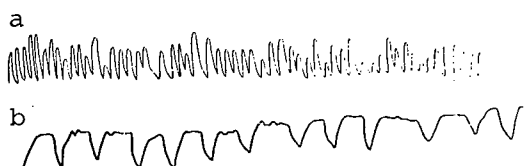
Figure 1.
Typical segments of ENG of the clonic (a) and tonic (b) types
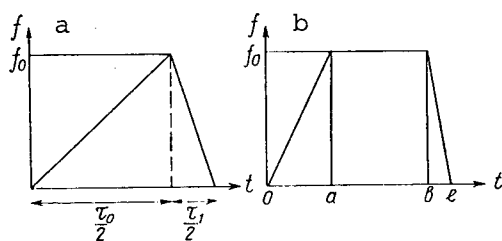
Figure 2.
Drawing of clonic (a) and tonic (b) types of nystagmic movements

$\tau_0/2$ $ob)$ slow phase duration

$\tau_1/2$ $bc)$ rapid phase duration
$f_0)$ amplitude of nystagmus

In this regard, it is interesting to analyze the spectrum of individual nystagmic movements of the clonic and tonic types (Figure 1) as a function of change in relationship of fast and slow phases. The slow phase of nystagmus is the first eye movement in response to vestibular stimulation, after which there is a rapid phase that returns the gaze to the base position. Clonic and tonic nystagmic movements have different relationships between duration of rapid and slow phases [2].

I. Let us consider the clonic type of nystagmic movement (Figure 2a).

Such nystagmus can be described as follows:

$$f(t) = \begin{cases} \dfrac{2f_0}{\tau_0}t, & \text{if } 0 \leqslant t \leqslant \dfrac{\tau_0}{2} \\ \dfrac{2f_0}{\tau_1}\cdot\left(\dfrac{\tau_0}{2}+\dfrac{\tau_1}{2}-t\right), & \\ \text{if } \dfrac{\tau_0}{2} \leqslant t \leqslant \dfrac{\tau_0}{2}+\dfrac{\tau_1}{2}. \end{cases}$$

In the segment in question, Fourier's odd function $f(t)$ series has the following appearance:

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$$f(t) = \frac{2f_0}{\pi^2} \frac{\tau_0}{\tau_1} \left(1 + \frac{\tau_1}{\tau_0}\right)^2 \times$$

$$\times \sum_{n=1}^{N} \frac{1}{n^2} \sin \frac{\pi n}{1 + \frac{\tau_1}{\tau_0}} \sin \frac{2\pi n}{\tau_0 + \tau_1} t.$$

Let us state that $\Phi = \frac{\tau_1}{\tau_0}$. Then, considering that $\tau_0 + \tau_1 = T$, we shall have:

$$f(t) = \frac{(1 + \Phi)^2}{\Phi} \sum_{n=1}^{N} \frac{1}{n^2} \sin \frac{\pi n}{1 + \Phi} \times$$

$$\times \sin 2\pi n \frac{t}{T}.$$

Thus, the amplitude of the nth harmonic at a given Φ will be:

$$A_n(\Phi) = \frac{(1 + \Phi)^2}{\Phi} \frac{1}{n^2} \left| \sin \frac{\pi n}{1 + \Phi} \right|. \quad (1)$$

II. Let us consider the tonic type of nystagmus (Figure 2b).

A tonic movement can be defined as follows:

$$f(t) = \begin{cases} \frac{f_0}{a} t, & \text{if} \quad 0 \leqslant t \leqslant a, \\ f_0, & \text{if} \quad a \leqslant t \leqslant b, \\ \frac{f_0(l - t)}{l - b}, & \text{if} \quad b \leqslant t \leqslant l. \end{cases}$$

In the segment in question, Fourier's odd function $f(t)$ series has the following appearance:

$$f(t) = \sum_{n=1}^{N} b_n \sin \frac{\pi n}{l} t.$$

Hence

$$f(t) = \frac{2f_0}{\pi^2} \sum_{n=1}^{N} \frac{1}{n^2} \left(\frac{l}{a} \sin \frac{\pi n a}{l} + \right.$$

$$\left. + \frac{l}{l - b} \sin \frac{\pi n b}{l} \right) \times \sin \frac{\pi n}{l} t.$$

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Let us introduce the following designation:

$$\Phi_1 = \frac{a}{l}; \quad \Phi_2 = 1 - \frac{b}{l}, \qquad (2)$$

Then

$$f(t) = \sum_{n=1}^{N} \frac{1}{n^2} \left(\frac{1}{\Phi_1} \sin \pi n \Phi_1 + (-1)^{n+1} \times \frac{1}{\Phi_2} \sin \pi n \Phi_2 \right) \sin \frac{\pi n}{l} t.$$

Thus, the amplitude of the nth harmonic at given value for Φ_1 and Φ_2, and accordingly for Φ will be:

$$A_n (\Phi_1 \Phi_2) = \frac{1}{n^2} \left| \frac{1}{\Phi_1} \sin \pi n \Phi + (-1)^{n+1} \right.$$

$$\left. \times \frac{1}{\Phi_2} \sin \pi n \Phi_2 \right|. \qquad (3)$$

With $a = b$, tonic nystagmus degenerates into a clonic type of movement. Analysis of the ENG established that the following will be the most representative values for Φ, which we shall designate hereafter as Φ_k: 0.03, 0.05, 0.07, 0.09, 0.011, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0. The first five values for Φ_k corresponding to tonic nystagmus and the others, to clonic type.

Below is the flowchart of the program algorithm for analysis of (1) and (3).
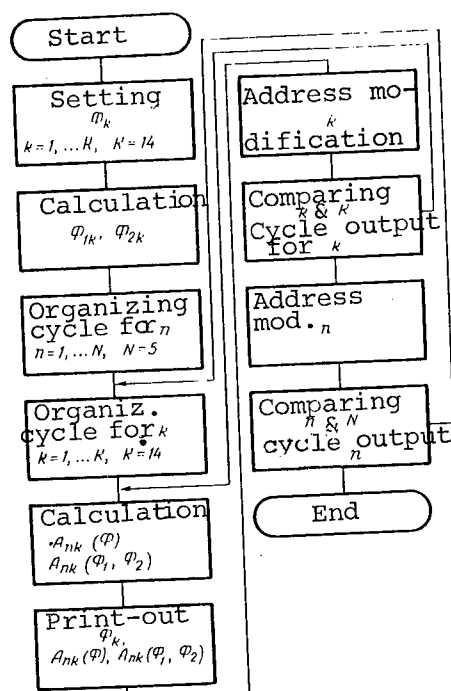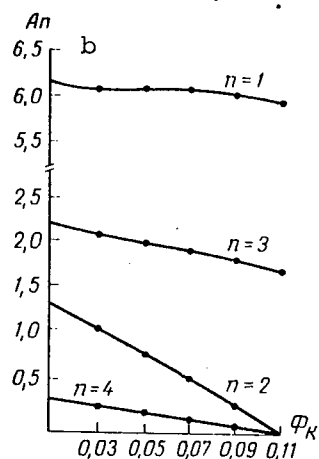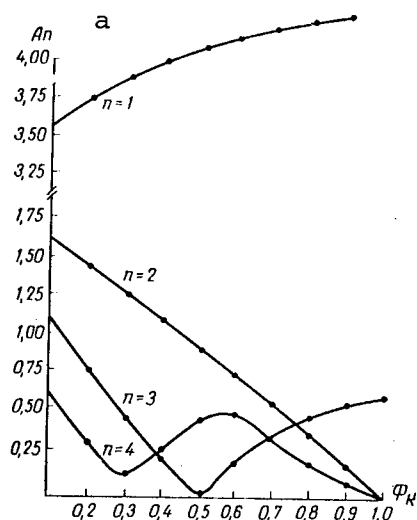
Figure 3.
Changes in harmonic components of
clonic (a) and tonic (b) nystagmus

Calculations confirmed that $A_{nk}(\Phi) = A_{nk}(\Phi_1\Phi_2)$ for clonic type of nystagmus.

Figure 3 illustrates amplitude A_n as a function of changes in Φ_k in the case of tonic and clonic nystamus.

Analysis of the nature of the different spectral lines leads us to conclude that, in the case of clonic and tonic nystagmus, the amplitude of the first harmonic is virtually independent of change in Φ_k; the amplitude of the second harmonic undergoes substantial change; the amplitude of the other harmonic elements can be disregarded. For this reason, it is expedient to use for diagnostic purposes the values for the frequencies of the first and second harmonics (f_1 and f_2), as well as the ratio of the square of amplitude of the second harmonic to the first, A_{2m}^2/A_{1m}^2

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RECOVERY OF SMALL AMOUNTS OF WATER IN THE DESERT

[Article by G. N. Sadikov]

[Text] Water is one of the main factors that limits self-contained survival time in an arid desert. Therma equilibrium at ambient temperatures above 33°C is maintained virtually solely at the expense of perspiration [4]. Extent of perspiration under desert conditions depends on many factors. To a large extent, it depends on man's behavior. With adequate water intake, the body can cope with heat without experiencing a water deficiency. However, if water intake is limited, dehydration develops. The rate of its development may vary, but in any case the degree of dehydration determines the duration of man's self-contained survival in the desert [2].

Studies involving a 3-day stay in the desert [3] revealed significant weight loss due to perspiration-related fluid loss. This was associated with 25-30% increase in viscosity of blood and 10-15% increase in peripheral blood hemoglobin content. It was shown tbat a daily ration of 1.5 ℓ water could provide, to some extent, for man's vital functions for 2-3 days. However, in spite of total restriction of motor activity, use of a tent made from a parachute and adherence to a wise schedule of fluid intake, all of the subjects lost 6-8% of their weight in 3 days as a result of dehydration. In order to prolong autonomous survival under these conditions it is necessary to make use of additional sources of water.

Methods

The proposed method of recovering water in a desert region is based on trapping water evaporated by desert plants. The excessive heat and water shortage in the summertime, salination of soil and phreatic water, mobility of sands, not infrequent cold winters, short spring and fall—all this developed special features in desert plants. Desert plants, particularly shrubs, have the amazing capacity of finding needed moisture under hot and dry conditions, and to protect themselves against excessive heating and drying. Many of them are characterized by absence of foliage, or else extremely insignificant development of leaf organs. Their root systems show complex ramifications and they are

extremely long (reaching 18 m in the black saxaul [Haloxylon genus]). However, in spite of the insignificant development of leaf organs, which is aimed at reducing evaporation, desert plants, like all others, constantly evaporate water into the environment in the course of their vital functions. To trap it, we propose that a waterproof hood be placed over the plant, and the water discharged by the plant will be condensed on its inside surface. After the closed hood is saturated with water vapor, the water condensed on the inside surface flows down and collects in its lower part. We used a polyethylene sack, 1×0.5 m in size (weight 80-90 g) as a closed waterproof hood. Depending on the size of the plant, 30 to 60 ml water collects in the bottom of the polyethylene bag in 1 h. Figure 1 clearly shows water condensed on the inside surface of the bag, and after collecting into droplets it flows to the bottom of the sack. The sack is sealed by tying a string around it or covered with sand to prevent evaporation of water near the root part of the plant.

Figure 1.
Trapping water evaporated by desert plants using a polyethylene sack

Results and Discussion

We selected several plant species for recovery of water: Agriophyllum minus--lesser "kumarchik," Chrosophora gracilis--graceful chrosophora, Salsola australis--southern saltwort, Salsola praecox--spring saltwart. The general distribution of these plant species is referable to Kara-Kumy, Mongolia and Iran. They have been described in detail previously [5]. The tested plants did not all yield identical gustatory properties. The water recovered from southern and early saltwort had good gustatory properties. It was pleasant to taste, odorless and colorless, and it was clear. Water recovered from the Agriophyllum minus had a tart flavor, resembling the taste of green tea; it was clear with a slight greenish cast; the water recovered from the Chrosophora gracilis was clear but bitter.

The organoleptic properties of water depended on how long the plant was kept in the sack: the longer the time, the poorer the gustatory properties of water. The plant died after 1 h in the sack, and after this the quality of the water worsened. In order to recover water without extraneous impurities, it is necessary to collect the water expressly at the early stages of condensation and drain it from the sack. For this purpose, a discharge valve must be installed at the bottom of the bag and the water should be removed as it accumulates, since expressly the first batches of water are the purest. The discharge valve also helps prevent sand mixing with water when the bags are reused.

At the present time, solar condensers have also been proposed to recover water under self-contained living conditions in the desert. Their design is based on a thin fil of water-repellent plastic. It is used to cover a hole about 1 m in diameter dug to a depth of 50-60 cm. Solar rays penetrating through the transparent film absorb moisture from the soil and, as it evaporates, it
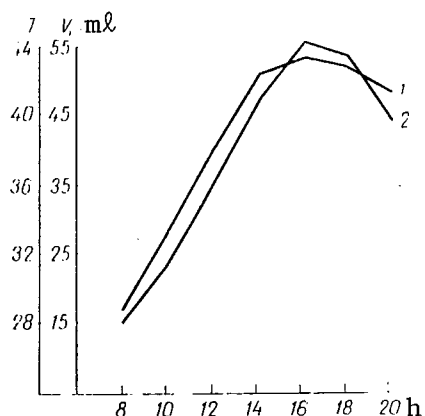
Figure 2.
Dynamics of recovery of small
amounts of water during dayling
in the desert
X-axis, time of test during
daylight, time of day; y-axis,
air temperature (T) and amount
of water recovered (ml)
1) air temperature
2) amount of recovered water

condenses on the inner surface of the film.
In 1 day, the condenser can yield up to
1.5 ℓ water [3]. This method can be
used in sand-covered deserts and when
ground water is not situated too deeply.
However, deserts are notable by a wide
diversity that is determined by the
natural features of different territories,
primarily the distinctions of their geo-
logical and geomorphological structure
[1]. Four main types of hot deserts are
distinguished according to their landform
features: sandy, rocky, clayey and saline.
Solar condensers are effective in sandy
deserts, and this is attributable to the
fact that the top layer of desert sands
is a zone of aeration. Sand dunes are
a sort of moisture reservoirs. Fresh water
accumulates at their bases and seeps into
the ground. The taller the dune, the more
moisture it accumulates and the closer it
is to the surface. Fresh water accumulates
the best in areas of coarse sand, where
there are declivities. A well dug near
the base of a sand dune will yield fresh

water. In rock, clayey and saline deserts, there is formation of insignificant
amounts of condensation moisture due to density of the ground, and for this
reason solar condensers are not effective. Moreover, ground water is usually
situated quite deep in such deserts. Under such conditions, phreatic water is
in the saturation zone, from which moisture in a vapor and droplet state is
replenished via capillaries. Plant roots capture it, utilizing it for nutrition
and transpiration. High temperatures, dry air and winds accelerate the rise of
moisture [1].

Figure 2 illustrates recovery of water as a function of temperature, and it
shows the direct dependence of water recovery on ambient temperature.

The method we propose for recovery of small amounts of water can be recommended
for life support of aircraft crews who have made a forced landing in the desert.
For this purpose, the portable emergency kit must include 4-5 polyethylene bags,
the weight of which would be 320-400 g. If we consider that one can recover
50-55 ml water from a bush of average size (at the site of our study, the
average height of bushes was 30-50 cm). the total amount of water collected in
a day could constituted 2.2-2.4 ℓ. Such a volume of water recovered daily would
help in the self-contained survival of aircraft crews following a forced landing
in the desert.

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BRIEF REPORTS

DYNAMICS OF PSYCHOLOGICAL STATE DURING PERFORMANCE OF PROFESSIONAL WORK CONSISTING OF AIR TRAFFIC CONTROL

[Article by A. F. Denisov]

[Text] Analysis of work dealing with the performance of air traffic controllers permits demonstration of its basic directions: professional screening, identification of states and monitoring them at different stages of the work day, problems of engineering psychology, etc. [1, 2, 6-8, 11, 12].

In these studies, considerable attention was given to dynamics of the body's functional state, including mental activity [1, 3-7, 11]. The importance of this question is obvious, since it is not everyone that is capable of maintaining an optimum level of efficiency that would assure the reliability and effectiveness of an operator's work in the presence of complicated equipment, heavy air traffic and considerable occupational stress.

Methods

We studied for several years the dynamics of mental state of air traffic controllers exposed to professional work loads related to air traffic control (ATC). We used the following methods: Luscher's color test (indicator of anxiety and coefficient of activity),* measurement of static tremor, measurement of dynamic tremor (coefficient of impulsiveness),** determination of perspiration with the Mishchuk instrument; tapping test (overall index and parameter of endurance),*** anomaloscopy method (after Plishko [9]).

We tested 70 air traffic controllers up to 35 years of age, with average work tenure in ATC of 7 years (a total of 310 tests were performed).

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*The coefficient of activity was derived on the basis of relationship in the series of preferences of "active" and "passive" colors.
**The coefficient of impulsiveness was determined from the ratio of number of errors in going through the tremometer maze to time spent on going through the maze.
***The endurance parameter reflects the ratio of number of taps in the last 10 s to the number of taps in the first 10 s.

Table 1. Dynamics of parameters of psychological state in different groups of air traffic controllers

Test period	Group	Statistical parameter	Anxiety, score bef.	Anxiety, score aft.	Impulsiveness coefficient, score before	Impulsiveness coefficient, score after	Endurance index in tap. test, score before	Endurance index in tap. test, score after	Static tremor* before left hand	Static tremor* before right hand	Static tremor* after left hand	Static tremor* after right hand	Perspiration, kΩ before right hand	Perspiration, kΩ before left hand	Perspiration, kΩ after right hand	Perspiration, kΩ after left hand
1980	1 (n=15)	M	3,6	3,8	0,82	0,93	1,06	1,01	3,8	3,3	4,8	4,9	95	280	277	388
		±m	0,3	0,3	0,05	0,04	0,02	0,02	0,55	0,66	0,5	0,5	22	65	55	61
	2 (n=15)	M	3,3	3,7	0,90	1,15	0,88	0,95	5,8	6,1	7,6	6,2	320	538	388	571
		±m	0,4	0,3	0,06	0,08	0,02	0,03	0,5	0,4	0,6	0,5	80	108	65	112
		P	<0,01		<0,05		<0,01		<0,05				<0,05			
1983	1 (n=20)	M	3,5	3,1	1,76	1,37	0,97	0,96	22,6	23,8	28,1	26,4	773	479	715	470
		±m	0,2	0,3	0,10	0,08	0,02	0,02	2,1	2,5	2,3	2,2	120	104	106	110
	2 (n=20)	M	3,8	4,5	1,50	1,62	0,91	0,84	20,8	20,6	27,3	22,0	1046	1176	788	828
		±m	0,4	0,3	0,07	0,06	0,03	0,02	2,5	2,3	3,1	2,6	245	260	143	182
		P	<0,01		<0,05		<0,05						<0,05			

*In 1983, tremor was measured with an electronic counter, and for this reason absolute values are higher.

Note: Before indicates before start of shift and after, after end of work.

Table 2. Changes in psychological parameters under the effect of different work loads (M±m)

Parameter	Group 1 heavy load after shift	Group 1 heavy load change	Group 1 light load after shift	Group 1 light load change	Group 2 heavy load after shift	Group 2 heavy load change	Group 2 light load after shift	Group 2 light load change
Anxiety, score	4,1±0,6	−0,9±0,3	3,0±0,5	−0,9±0,2	4,2±0,5	1,7±0,6	3,6±0,5	−1,0±0,6
Activity index, score	−0,3±0,7	−0,3±0,4	0,2±0,5	−1,7±0,6	−0,8±0,5	0,2±0,4	−0,9±0,5	1,7±0,5
Functional state on anomaloscope, score	2,3±0,1	0,1±0,3	1,8±0,7	−0,4±0,7	1,6±0,6	−0,1±0,3	1,1±0,6	−0,5±0,3
Impulsiveness index, score	1,3±0,2	−0,1±0,2	0,9±0,2	−0,2±0,2	1,7±0,5	−0,1±0,1	1,8±0,2	0,4±0,1
Work capacity in tapping test, score	276±25	17,0±0,1	263±13	20,8±0,7	223±20	7,2±1,5	238±30	−17,0±5,3
Endurance index in tapping test, score	1,0±0,1	−0,1±0,1	0,98±0,02	0,06±0,08	0,91±0,1	0,02±0,05	0,80±0,1	−0,1±0,1
Tremor of left hand (number of taps)	23,5±4,3	−8,0±4,9	17,7±1,4	−5,7±3,3	31,5±6,7	9,7±5,3	15,7±5,0	−5,0±3,5

Results and Discussion

The subjects were divided into two groups: the 1st consisted of controllers who coped well with their job and the 2d, those who did not perform their work well. Performance was determined by the method of expert ratings. Five people who differed in professional rank served as experts. They made the evaluations by means of a questionnaire that was developed, which permitted detection of various aspects of professional work. Ultimately, a mean rating was derived for each controller.

Analysis of the data (Table 1) shows that when air traffic was heavy in 1980, both groups of subjects presented a state of prestart tension with significant mental changes after completing their shift. These changes were in different directions: significant increase in anxiety and coefficient of impulsiveness in the 2d group of controllers; there was more increase in tremor in the 1st group.

The differences between test results in the summer of 1983 when there was heavy air traffic, referable to the 1st and 2d groups, were more demonstrative. In the 1st group, the parameter of anxiety before the shift was lower than in the 2d group, and it dropped even more after ATC work. Their coefficient of impulsiveness was higher, but it dropped after the shift. Concurrently, the coefficient of endurance was higher in the "prestart" state, and it remained virtually the same after ATC work. Reactivity (perspiration) was greater in the 1st group both before and after the shift. These differences are indicative of greater activation of this group of controllers before the shift and a high level of efficiency throughout the period of ATC work.

It was important to determine how a difference in work load during the shift affects the dynamics of current psychological state.

For this purpose, we formed two subgroups in each group, a and b; in the 1st group they included subjects who performed well with heavy and light work load, respectively; in the second group, those who did not perform well with heavy and light work load (Table 2). We considered control of 50 or more aircraft per shift to be a heavy work load, and 35 or less aircraft, a light work load.

According to our results, a heavy work load elicited more appreciable changes in psychological parmaters in the 2d group of controllers. As compared to the 1st group, they showed an increase in anxiety and a somewhat lower coefficient of acitvity, the absolute value of which was also lower. There was worsening of the functional state of the 2d group of controllers according to results of anomaloscopy, with a lower absolute value for it. The overall index according to the tapping test was lower, and an insignificant increment was observed after the shift. In addition, we demonstrated a considerably lower coefficient of endurance in the tapping test, greater increase in hand tremor with high absolute values for this parameter. All this is indicative of significant work tension in the 2d group of controllers with heavy ATC work loads. An analogous difference in parameters between the 1st and 2d groups of subjects is observed with small work loads.

These differences are indicative of ineffective adaptation of the 2d group of controllers both to relative calm and considerable work loads.

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We then analyzed the dunamics of mental state as a function of medical status. We used two subgroups of controllers: a) with diseases of the gastrointestinal tract (GIT; 7 people) and b) with diseases of the cardiovascular system (CVS; 10 people).

Analysis of the differences between these samples and a group of essentially healthy controllers revealed that there were certain tendencies toward differences in a number of parameters, although reliable differences were not found. Thus, in controlles with GIT diseases, there were more significant changes in psychological state than in healthy subjects. This was manifested by an increase in anxiety, worsening of functional state according to anomaloscope data, diminished efficiency, increased tremor of the hands. In controllers with CVS diseases, appreciable differences were demonstrable with respect to two parameters reflecting autonomic regulation. In these subjects, there was considerable increase in perspiration after the work shift and an increase in tremor of the left hand, with decrease in tremor of the right hand.

Thus, the medical status also had some influence on psychophysiological tolerance to professional ATC work loads.

The obtained data are indicative of emotional tension in controllers during ATC work, more so in the 2d group of subjects. They presented emotional tension with both insignificant and considerable work loads, which is indicative of the adverse effect on this group of controllers of both a calm work situation and heavy work loads. Greater emotional tension was also observed in controllers with GIT diseases, as well as with CVS diseases.

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CONCEPTIONS OF AUTOMATION OF STUDIES OF OPERATOR PERFORMANCE

[Article by V. M. Drozhzhin]

[Text] We discuss here some possibilities with respect to organizing the study of operator (pilot) performance on a model with use of computer engineering.

The following theses are the basic conceptions for systems that control in real time:

Use of microprocessors and microcomputers to process analog data and to control

Feasibility of using intellectual signal input and output devices

Enhancement of reliability of control by use of semipermanent storage devices

Parallel and distributed data processing in multimicroprocessor environment

Flexibility of structures in multimicroprocessor environment

Feasibility of system transformation, from one microprocessor per curve (or group of curves) to n microprocessors per curve

Homogeneity of equipment used

Unified guidelines for organizing the computing process on different computers

Low level of systemic outlays

It is expedient to organize the multimicroprocessor environment according to the hierarchic principle: Bottom level--recording all signals and their distribution; middle level--parallel processing of individual signals (groups); top level--integral processing.
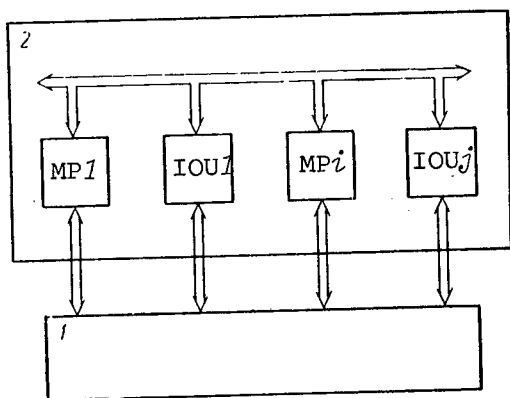
Figure 1.
Structure of single-level multi-processor system
  1) object of control (or physical model)
  2) homogeneous multiprocessor computing complex
MPi) ith microprocessor
IOUj) jth input-output unit

It is expedient to develop programs in speed-efficient languages.

Figures 1 and 2 illustrate examples of organization of microprocessor automation systems. In a relatively simple structure (see Figure 1), there is implementation of the algorithm for parallel processing of input signals on i microprocessors, and one of them may be the central one. In a more complex structure (see Figure 2), there are three (bottom, middle and top) levels of processing. The efficiency of using such systems is discussed elsewhere [1, 2].

The following basic theses were adopted for development of systems for analysis of computer file data:

Development of a large data base on 100 Mbyte or larger disks

Distribution of data in local (functional) bases that would fix the data in the interexperiment period, make adjustments for a specific experiment, gather experimental data, storage in the computer file

Development of flexible means of access to data for a nonprofessional consumer

Development of special packs and use of standard ones for mathematical analysis

Graphic display of data

As we have already indicatec above, the solution of these problems is effective with use of computer of the same class as for data processing in real time. It should be noted that use of the same computers for both real time control and analysis of data in the computer file would accelerate work as well on future development of systems and methodology for automation of research.

The above conceptions have been implemented in the system of automation of physiological studies. The first line of the system consists of four SM-1800 microcomputers interconnected by an IRPR parallel interface (Figure 3). The structure of the above computer complex is hierarchic (two levels); three computers are used on the bottom level, and they effect preliminary processing of the cardiogram (after Nehb), rheogram (volume and differential), pneumotachogram, systolic pressure in the earlobe, myogram, as well as data on gravity overloads. On the top level, one computer makes an integrated evaluation of state and work capacity of the operator; it also receives and processes signals referable to the operator's temperatures, parameters of tracking an object, sensors for turning on and recording a photic stimulus, etc.
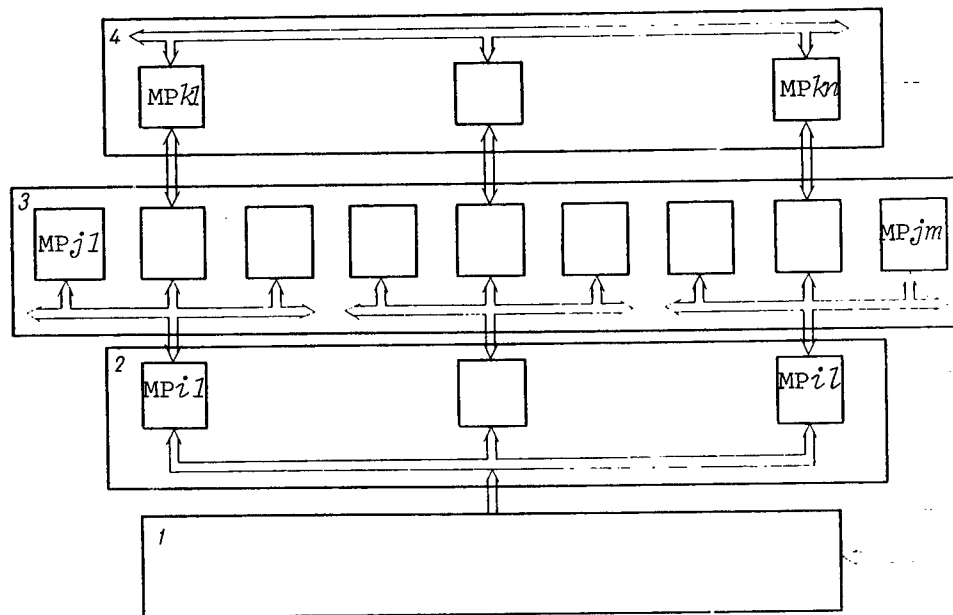
Figure 2. Structure of three-level multiprocessor system

1) object of control (or physical model)
2) intelligent input-output units (MPil)
3) functional microprocessor environment (microprocessors MPjm)
4) microprocessor environment (microprocessors MPkn) for integral processing
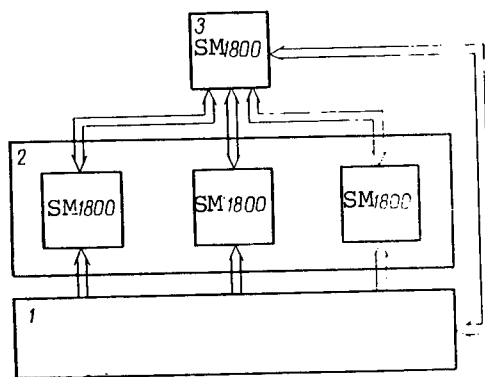
Figure 3.
Structure of two-level hierarchic syautomation system based on SM-1800 microcomputer
1) object of control (or physical model)
2) bottom level SM-1800 computer
3) top level SM-1800 computer

Preprocessing of physiological curves at the pace of the experiment comprises the following parameters:

Isolation of R-R intervals, computation of frequency of of cardiac contractions (HR--heart rate), arrhythmia tag, read-out on rhythmogram screen (it is possible to set a variable number of intervals for averaging R-R intervals)

Presence of extrasystoles (ventricular or atrial type)

Computation of ejection time, stroke and circulation volume (after Kubicek)

Computation of respiratory rate and respiratory minute volume

Calculation of systolic pressure in earlobe

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Calculation of mean amplitude of myogram for fixed periods of time

Calculation of mismatches and evaluation of work capacity in object tracking mode

Calculation of latency period (response to photic stimulus)

Calculation and evaluation (mean, maximum, etc.) of skin and rectal temperatures

As a result of processing physiological and other information, the basic current physiological parameters of three subsystems of the body (cardiovascular, respiratory and sensorimotor), critical information about presence of various extrasystoles, decline of some parameters below the permissible level, as well as the integral parameter--degree of risk characterizing body tension--are displayed on the screen of the chief of the experiment.

On the screen of the engineer's workplace, the technical parameters of the study are displayed: scheduled and actual plots, overload mismatch, time of experiment.

Programs have been developed and are executed under the control of the DOS-1800 disk operating system.

Original control programs and a scheme for processing interruptions analogous in all computers of the complex are used to organize the computing process in real time. High-speed drivers have been developed to service external units of the system.

A special editor and program libraries are used to produce and keep up the data base.

Programs for analysis of stored data include computation of basic elementary parameters and functions of mathematical statistics.

The executed system for automation of a complicated study is characterized by the following data: 20 recorded signals, 200 μs analog-to-digital conversion (with consideration of operation of program driver), 1 kHz maximum speed of signal interrogation, 1/60 Hz minimal speed, 1 s output of control and integral parameters of processes, $5 \cdot 10^3$ byte/s actual speed of data transmission between computers.

The different self-contained components of this development can be used for analogous applications, for example, package of applied programs (PAP), evaluation of state and work capacity of operator (PAP-function), PAP for control of research data base (PAP-rdinf).

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EFFECT OF ADEQUATE STIMULATION OF VESTIBULAR ANALYZER ON ACOUSTIC EVOKED
POTENTIALS WITH AVERAGE LATENCY PERIOD

[Article by V. P. Ovsyanik, E. A. Bakay, V. V. Gurik, R. Sh. Karimov,
S. L. Udovik, and L. S. Kovalenko]

[Text] Our objective here was to analyze changes in amplitude of mean-latency
period acoustic evoked potentials (MAEP) before and after stimulation of the
vestibular analyzer (VA) in subjects differing in vestibular stability.

Methods

The studies were conducted in a shielded acoustic chamber and involved 34
subjects who were essentially healthy and had normal hearing. They were
divided into three groups by the Bryanov method, in accordance with the threshold
of vestibulosomatic response as determined by the K index. The 1st group con-
sisted of 4 people with K-2, the 2d 8 people with K-6 and the 3d, 22 people with
low vestibular stability (K-12 and K-24).

As equipment for these tests, we constructed a device consisting of an
elecgric revolving chair and unit for recording and analyzing evoked bio-
electrical activity (EBA). The device included a specialized generator of
acoustic stimuli, amplifier of bioelectric potentials with 0.8 μV effective
level of input noise in the 30-160 Hz band of isolation of MAEP and automated
system (AS) based on an Elektronika 60 microcomputer to single out the acoustic
evoked potentials (AEP).

The 10-20 system was used to measure bioelectric activity: the active electrode
for Cz current, silent M_2 and ground on the forehead. Resistance between the
active and ground electrodes did not exceed 10 kΩ. The audio stimuli were
delivered at a frequence of 5 pulses/s to the side where the silent electrode
was placed. We used acoustic stimuli at acoustic pressure of 70 dB in relation
to $2 \cdot 10^{-5}$ Pa lasting 3.5 ms, at filling frequency of 1 kHz and 0.5 ms anterior
and posterior fronts. Frequency of digitizing analogue signals of EBA was
2.5 kHz at the input into the AS.

Prior to vestibular stimulation, in all groups of subjects we singled out
(by means of accumulation of bioelectric activity) 5 successive MAEP, and

calculated mean and error of mean amplitudes and latency periods of the most typical cochleomyogenic components--0_a, P_a and 0_b. In order to stabilize the margin of error in measurement of components, the number of files for each of the isolated MAEP was selected in such a way that coefficient M, which determines the ratio between effective levels of stored post- and pre-stimulus runs of potentials would equal 4:

$$M = \frac{\sqrt{\sigma_{\text{п}}^2 - \sigma_{\text{пр}}^2}}{\sigma_{\text{пр}}},$$

where $\sigma_{\text{п}}$ and $\sigma_{\text{пр}}$ are standard deviations of stored post-stimulus and, accord÷ingly, pre-stimulus runs of bioelectric activity. Each run lasted 60 ms.

Vestibular stimulation was produced by 2-min rotation at 180°/s on the electric revolving chair after which it was stopped; the head was bent down at an angle of 30° during the procedure. The intensity of the stop stimulus was 270°/s². After the chair stopped, we isolated the MAEP (number of accumulations 512) and measured the amplitudes of the tested components of MAEP

The probability of reliability of differences in amplitudes of MAEP components before and after vestibular stimulation was assessed by means of the criterion of paired comparison accoridng to the value of the statistical t coefficient. For this purpose, we determined relative change in amplitude of components (B) using the following formula:

$$B = \frac{A_n - \overline{A}_g}{\overline{A}_g},$$

where A_n is amplitude of component after rotation, $\overline{A}_g$ is mean amplitude of the same component before rotation. After this, we determined the mean value for $\overline{B}$, standard deviation σ_B, as well as mean error $m_{\overline{B}}$, for subjects in each group. Statistical coefficient t of difference was calculated by the formula:

$$t = \frac{\overline{B}}{\sigma_B} \sqrt{n - 1},$$

where n is the number of subjects in the group.

Results and Discussion

This study enabled us to demonstrate a reliable increase in amplitudes of P_a and 0_b components of MAEP in the 2d group of subjects, and of components 0_a, P_a, 0_b for the 3d group (after vestibular stimulation) (Figure 1; see Table). At the same time, the 1st group of subjects presented no reliable differences in MAEP parameters before and after vestibular stimulation.

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Mean $\overline{B}$, mean error $m_{\overline{B}}$ and probability of reliability of difference in amplitudes of components O_a, P_a, O_b of MAEP isolated before and after VA stimulation in subjects of different groups

Group	O_a			P_a			O_b		
	$\overline{B}$	$m_{\overline{B}}$	P	$\overline{B}$	$m_{\overline{B}}$	P	$\overline{B}$	$m_{\overline{B}}$	P
1	-0,325	0,362	0,6	0,01	0,12	0,2	0,16	0,062	0,1
2	1,24	1,36	0,8	0,77	0,30	0,99	0,41	0,28	0,95
3	1,83	1,06	0,99	2,9	1,45	0,99	2,24	0,81	0,999

μV
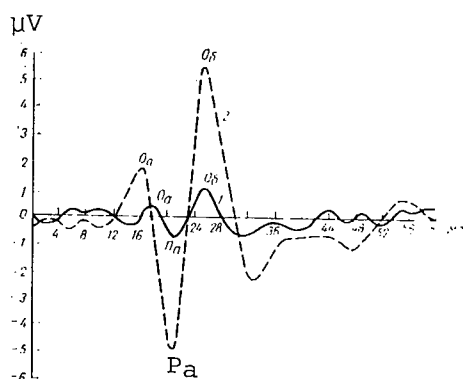
Figure 1.
Acoustic evoked potential with mean latency period in subject P. K. in response to acoustic stimulus of 70 dB
1) before rotation
2) after rotation

We were also impressed by the fact that $\overline{B}$ differed in different groups. To assess the reliability of difference in coefficient $\overline{B}$ for each component of AEP in the different groups, we also used the statistical criterion, but the value of t was determined by the following formula:

$$t = \frac{\overline{B}_i - \overline{B}_j}{\sqrt{m_{\overline{B}_i}^2 - m_{\overline{B}_j}^2}},$$

where $\overline{B}_i$ and $\overline{B}_j$ are mean values of B in compared groups i and j, $m_{\overline{B}i}$ and $m_{\overline{B}j}$ are errors of mean $\overline{B}_i$ and $\overline{B}_j$, respectively.

As shown by calculations of component O_a, probability of reliability of difference in the 2d and 3d groups of subjects is 0.3, for component P_a P = 0.8 and for component O_b it is 0.9. Consequently, in separating the 2d and 3d groups of subjects, O_b was found to be the most informative, and in separating the 1st and 2d groups, this applied to P_a (P = 0.9); for component O_b, P = 0.75 and for component O_a, P = 0.65. A high probability of separation (P>0.9) is obtained for subjects in the 1st and 3d groups with use of any of the tested components.

For applied purposes, the dynamics of changes in parameters of MAEP in the presence of development of the symptoms of motion sickness are of definite interest. For this reason, we conducted additional studies using some subjects from each group, and they consisted of submitting them to 3-fold adequate VA stimulation for 2 min at 3-min intervals between stimuli. We recorded the MAEP for 1.5 min after each cycle of VA stimulation, as well as in the 5th and 10th min after vestibular stimulation. We analyzed changes in amplitude of MAEP components, as compared to their values before vestibular stimulation. For this purpose, we determined coefficient B using the following formula:

Figure 2.

Typical appearance of change in coefficient B for components O_a (a), P_a (b) and O_b (c) in different subjects during 3-fold rotation and in the aftereffect period

1-3) subjects of 1st-3d groups, respectively

I-III) cycles of rotation

$$B = \frac{A_{n\,i} - \bar{A}_g}{\bar{A}_g}$$

where A_{ni} is amplitude of the appropriate component after the ith cycle of rotation, as well as in the 5th and 10th min of the aftereffect period.

The value of B was taken as zero with change in amplitude of relevant component not exceeding the confidence interval calculated for the amplitude of this component on the basis of the MAEV obtained prior to adequate stimulation.

Figure 2 illustrates the typical appearance of changes in B in different subjects from each group, for the tested components of MAEP. As we see, the relative changes in all MAEP components each present their own distinctions in different groups of subjects. After the second cycle of rotation, the amplitude of components did not change or diminished insignificantly in the 1st group of subjects; it increased in the 2d group and showed significant decrease in the 3d group. It should be noted that we observed signs of vestibulovegetative dysfunction after the second cycle of rotation in most subjects of the 3d group, and for this reason they were not submitted to a third cycle of rotation.

These studies indicate that vestibular stimulation of the chosen intensity leads to reliable change in amplitude of components of acoustic evoked potentials of average latency period. Reliable differences are particularly significant in individuals with low vestibular stability. At the same time, the level and dynamics of changes in amplitudes of MAEP components after one and several cycles of adequate VA stimulation differed reliably in subjects differing in vestibular stability.

EVOKED POTENTIALS WITH LONG LATENCY PERIOD IN MAN WITH EXPOSURE TO LINEAR ACCELERATIONS

[Article by V. P. Ovsyanik and S. L. Udovik]

[Text] In the last decades, much attention has been given to questions of investigation and evaluation of the state of analyzer systems (acoustic, visual and others) according to parameters of evoked bioelectrical activity (EBA) under the effect of appropriate adequate physical stimuli.

Our objective here was to single out complex evoked potentials (CEP) in the bioelectrical activity (BA) of the human cerebral cortex, which were induced by linear accelerations.

Methods

We used a stomatological chair to submit subjects to linear accelerations, and it was equipped with a movement control unit. Duration of chair movement (duration of stimulus) T_S varied from 50 to 600 ms. Displacement constituted 1 cm per 100 ms stimulation. The chair could be moved both up and down. Duration of accelerations and deceleration of the chair constituted 20-30 ms with different Ts. Movement of the chair with a subject weighing 80 kg down generated acceleration of 0.2-0.3 m/s^2, and with movement up- from 0.8 to 1 m/s^2 depending on T_S.

To derive EBA, we placed electrodes as follows: active--vertex (point Cz in the 10-20 system), neutral electrode--mastoid (M_2) and ground--on the forehead. Interelectrode resistance did not exceed 5 kΩ.

Storage of EBA synchronized with the start of chair movement was effected by means of an automated system (AS) developed on the basis of an Elektronika 60 microcomputer. AS enables us to single out EBA and automatically measure the aggregate of time, energy and amplitude parameters of EBA [1].

We selected a quasioptimum band for filtration of analyzed signals, of 0.1-30 Hz, on the basis of results of preliminary experiments, in which the width of energy spectra of EBA on different levels was assessed in relation to the maximum. In this band, effective level of intrinsic noise of the amplification unit scaled to the input constituted 017 µV.

We selected 5.5 s as the stimulus recurrence period, since a decrease in amplitude of EBA components was observed with lower values.
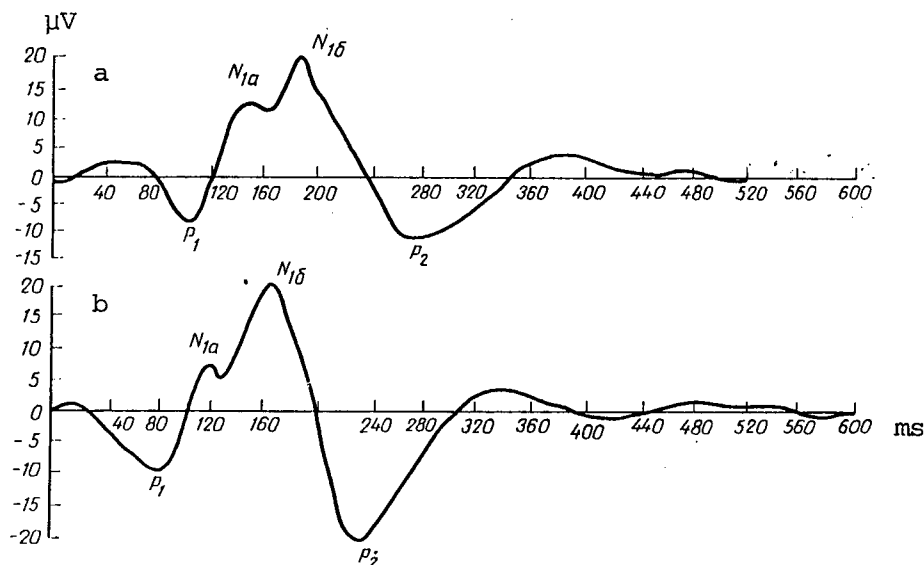
Figure 1. Averaged CEP obtained on healthy subjects in seated position,
$T_S = 100$ ms
Here and in Figures 2-4: x-axis, time (ms); y-axis, amplitude (μV).
Here and in figure 4: a) movement up, $a = 0.8$ m/s^2
                        b) movement down, $a = 0.2$ m/s^2

Frequency of averaging prestimulus and poststimulus BA varied from 12 to 45 times, depending on conditions of adherence to constant coefficient M (M = 5), which determines the relationship between effective levels of stored post- and prestimulus BA runs:

$$M = \frac{\sqrt{\sigma_{\text{пс}}^2 - \sigma_{\text{ппс}}^2}}{\sigma_{\text{ппс}}},$$

where $\sigma_{\text{пс}}$ and $\sigma_{\text{ппс}}$ are standard deviations of post- and prestimulus BA stored, respectively.

Duration (T) of pre- and post-stimulus runs was selected at 600 ms, while frequency of digitization of analogue signals of BA at the input to the computer was 250 Hz.

We conducted four series of tests. In the first and second series, we worked with healthy subjects who sat in the chair with their head tilted back (at an angle of 10% from the vertical line) and to the right (or left) shoulder (45°), respectively. In the third and fourth series, we conducted analogous tests, but on subjects with functional impairment of the vestibular analyzer (VA).

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In control studies to assess the effect of electromagnetic induction, an equivalent load (B = 10 kΩ and C = 47 pF, connected in parallel, attached to the chair) was switched on at the inputs of the amplifer. The subject was placed next to the chair to assess the effect on BA of acoustic stimuli generated by movement of the chair.

All of the tests were conducted in a dark room, the subjects keeping their eyes shut, to rule out the influence of oculomotor potentials on CEP.

Each of the subjects were tested 3-5 times both per day and on different days. A total of 13 healthy individuals (5 women and 8 men 28-45 years of age) and 2 people with functional impairment of the VA (elimination of labyrinthine function due to prior cerebrocranial trauma) participated in the tests.

Results and Discussion

The results of these studies revealed that with exposure to linear accelerations of the chosen range it is possible to single out CEP on the encephalogram. There was good reproducibility of parameters obtained under identical conditions for the same subject.

CEP averaged for 13 subjects with upward movement in the 1st series of tests (T_S = 100 ms) is illustrated in Figure 1a. CEP contains three components: P_1, N_1 and P_2. Table 1 lists the parameters of averaged CEP. Positive component P_1, which is not very pronounced in a number of cases, has a latency period (LP) of 106±5 ms; LP of the negative high-amplitude (up to 35 µV from the isoline) component N_1 is 130-210 ms. This basic negative component splits in most cases into two components, N_{1a} and N_{1b}, or else a plateau is formed in the place of component N_{1a}. It should be noted that the amplitude of N_b was lower than that of N_{1a} in 2 of the subjects. P_2 had an amplitude of up to 26 µV and LP of 274±15 ms. Maximum spread of amplitude of N_1P_2 in some subjects reached 50 µV, although it was about 30 µV in most cases. With downward movement (T_S = 100 ms) analogous 3 components are observed (Figure 1b). However, LP (see Table 1) is shorter than with upward movement, while maximum spread of N_1P_2 amplitudes is greater.

Table 1. Parameters of averaged CEP (M±δ)

Direction of movement	Series	P_1		N_{1a}		$N_{1б}$		P_2	
		ampli-tude, µV	LP, ms	ampl., µV	LP, ms	ampl., µV	LP, ms	ampl., µV	LP, ms
Up	I	.8 (2—12)	106±5	13 (7—25)	144±7	21 (6—35)	189±8	12 (0—26)	274±15
	III	—	—	20 (24—27)	145±7	12 (5—23)	211±5	7 (2—15)	272±10
Down	I	10 (8—12)	84±4	8 (0—27)	117±5	22 (5—38)	160±8	22 (14—30)	227±12
	III	—	—	15 (10—20)	128±11	23 (12—32)	170±4	15 (5—30)	245±12

Note: Range of fluctuations given in parentheses.

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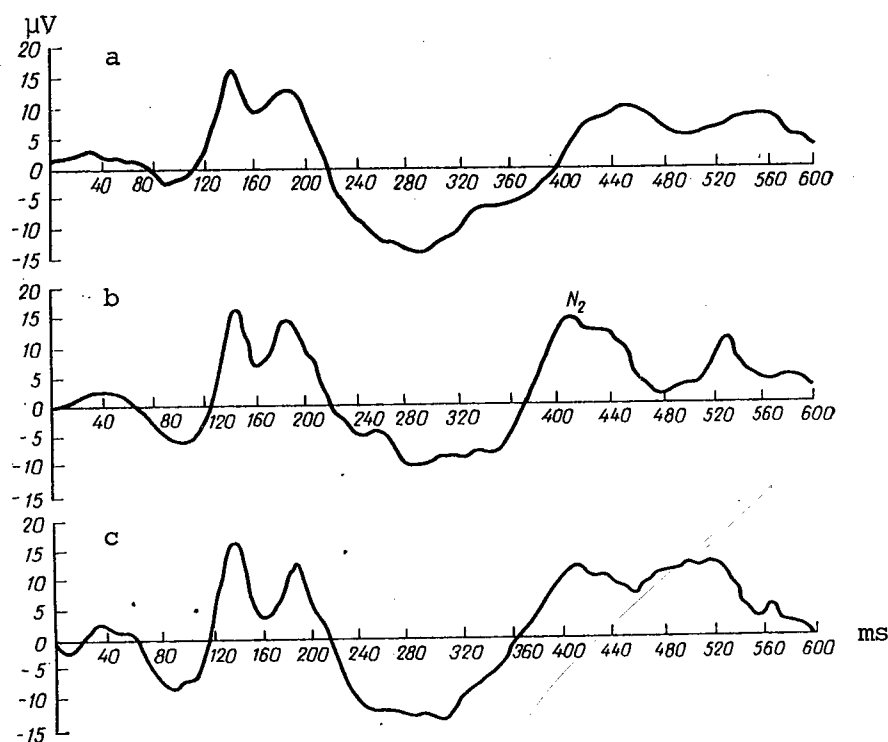
Figure 2. CEP obtained for subject K. S. in seated position with upward movement

a) T_S = 100 ms, a = 0.8 m/s^2 c) T_S = 600 ms, a = 1 m/s^2
b) T_S = 300 ms, a = 0.87 m/s^2

With change in T_S and insignificant differences in accelerations during movement up and down, we failed to demonstrate appreciable differences in appearance of CEP in the LP range of up to 300 ms (Figure 2). With T_S = 300 ms, there was appearance of negative component N_2 with LP 410-440 ms, amplitude 5-15 μV, and LP 470-490 ms with amplitude of 17-23 μV with downward movement. With T_S<200 ms, there was virtually no evoked potential during braking, probably due to adaptation to the stimulus. With upward and downward movements, LP of appearing component N_2 during deceleration constituted 110-140 ms and 170-190 ms, respectively, from the time the stimulus ended. To rule out the effect of braking on parameters of CEP, the main tests were performed at T_S = 100 ms. Use of T_S = 50 ms is inexpedient due to inadequate stability of parameters of the obtained stimuli.

The results of the second series of studies revealed that change in head position in relation to the vertical line leads to change in form and parameters of CEP (Table 2).

With head movement upward and to the right shoulder there was increase in amplitude and decrease in LP of N_{1a}, as a result of which component N_{1b} is seen, or a plateau is formed in the case when N_{1a} and N_{1b} merged with the

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head erect (Figure 3a and b). With the head tilted to the left shoulder, there was virtually no change in amplitude of components, while LP of N_{1a} diminished (Figure 3c). With head movement down and to the left shoulder, the changes were analogous to those observed with upward movement and tilt to the right shoulder. With the head tilted to the right shoulder, there was increase in LP of N_{1b}, while LP of N_{1a} did not change.
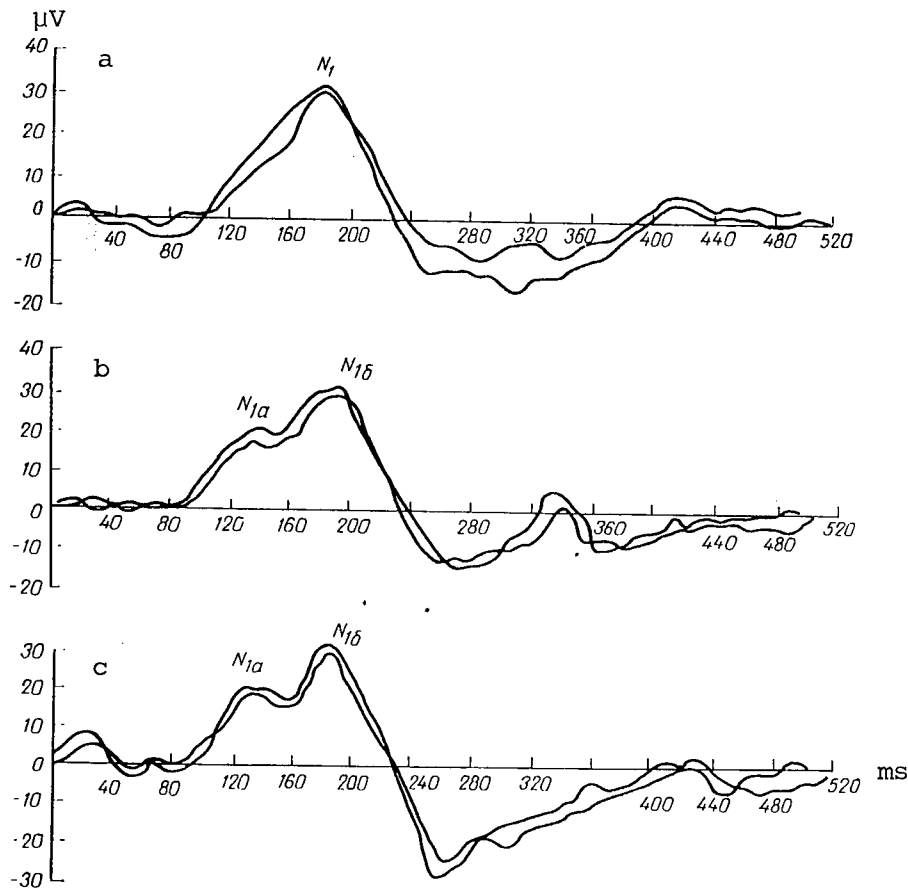
Figure 3. CEP obtained in subject S. L. in seated position with upward movement, $T_S = 100$ ms, $a = 0.8$ m/s^2
a) head erect
b,c) head tilted to right and left shoulder, respectively

In the subjects with impaired VA function in the 3d series of studies, LP of components N_{1a} and N_{1b} was longer than in healthy subjects with movement both up and down. With upward movement, there was a greater difference between LP of N_{1a} and N_{1b}.

With upward movement and head tilt to both the right and left shoulder (Figure 4; see Table 1) in subjects with impaired VA function in the 4th series, we observed increase in LP of N_{1a}. With downward movement and tilts to the left shoulder, we also observed extension of LP of N_{1a} in subjects with impaired VA function (see Table 2).

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Table 2. Qualitative changes in CEP with different head positions

Direction of movement	Head tilted	Series	N_{1a} ampl. µV	N_{1a} LP, ms	$N_{1б}$ ampl. µV	$N_{1б}$ LP, ms	Distinctions in area of LP of more than 200 ms
Up	To right shoulder	II	+	—	0	0	Additional component with LP 330–380 ms
		IV	+	+	—	—	380 мc 0
	To left sh.	II	0	—	0	0	0
		IV	0	+	0	+	0
Down	To right shoulder	II	—	0	+	+	Additional component with LP 300–400 ms
		IV	0	0	0	+	0
	To left shoulder	II	+	—	—	0	0
		IV	+	+	—	0	0

Key: +) increase   −) decrease   0) no change
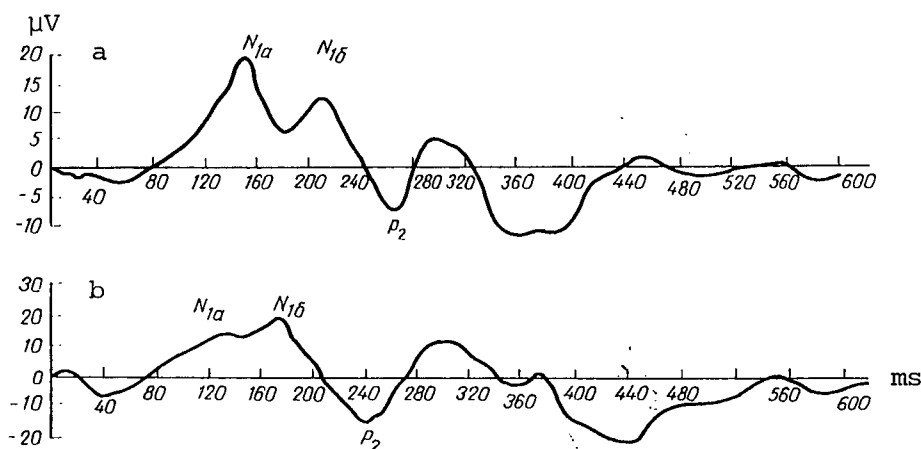
Figure 4. Averaged CEP obtained on two subjects with impaired VA function in seated position, T_s = 100 ms

Control studies pursued to assess the extent of effect of electromagnetic induction revealed that there is about a 2-fold increase in effective noise level in the post-stimulus accumulated run, as compared to prestimulus finding, and it constitutes a mean of 2.3 µV. Also, there is appearance of a negative peak with amplitude of ~4 µV in the LP region coinciding with duration of stimulus, which is apparently related to electromagnetic induction due to termination of the stimulus, i.e., switching the chair motor off. With downward movement, the motor does not operate, and this peak does not appear. Control measurements to assess the effect of acoustic factors on BA revealed increase in BA in the cumulative post-stimulus run, i.e., appearance of an acoustic evoked potential (AEP) of low amplitude, and the spread of N_1P_2 did not exceed 6 µV. Since the amplitude of CEP components exceeded significantly amplitudes due to electromagnetic induction and acoustic factors, the latter had an insignificant effect

on accuracy of measurement of CEP parameters. Nevertheless, the subjects wore earplugs while recording CEP to rule out the AEP contribution.

Thus, the methods used in this study enabled us to demonstrate appreciable differences in form of CEP obtained on healthy subjects with the head in different positions. Studies of individuals with impaired VA function revealed an increase in CEP latency period, as compared to values inherent in healthy subjects. When such individuals had their head in a different position, in relation to the erect position, the direction of changes in CEP LP was the opposite of that recorded on healthy subjects. This indicates that the VA has some effect on formation of CEP.

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HUMAN BLOOD LACTATE DEHYDROGENASE ISOZYME COMPOSITION WITH SINGLE EXPOSURE
TO ACUTE HYPOXIA, AND ITS LINK TO PHYSICAL WORK CAPACITY

[Article by T. V. Serebrovskaya, A. N. Krasyuk, and V. N. Fedorovich]

[Text] Regulation of biosynthesis of isozymes of lactate dehydrogenase (LDH)--
an enzyme that catalyzes the reversible reaction of converting pyruvate to
lactate--is one of the mechanisms that provides for adaptive coordination of
aerobic and anaerobic carbohydrate metabolism. It has been established that
LDH isozymes are present in tissues and organs mainly in five molecular forms.
It has been shown that there is prevalence of anode forms of the enzyme (LDH-1
and LDH-2) involved in control of aerobic glycolysis in tissues such as the
myocardium, red blood cells, brain and kidneys, whereas in skeletal muscles,
liver and skin there is prevalence of cathode forms (LDH-4 and LDH-5), which
are responsible for regulation of anaerobic glycolysis [15, 19]. Conformity
of the sets of isozymes to metabolic requirements of tissues is obtained by
regulation of LDH monomer synthesis [16, 18]. As a result of acute hypoxia
conditioning, there is increase in LDH-1 and LDH-5 activity in blood plasma
[8], whereas in the period of adaptation to high altitude the isozyme composi-
tion of LDH is characterized by loss of the rapidly moving fractions (LDH-1
and LDH-2) and activation of anaerobic fractions [14]. All these data were
obtained from studies of animals.

Our objective here was to investigate the changes in LDH isozyme composition
of human red blood cells during conditioning with acute hypoxia and to
explore the possible links between these changes and physical work capacity.

Methods

This study was conducted on 8 healthy men 20-28 years of age differing in
level of physical conditioning: maximum oxygen uptake ($\dot{V}_{O_2}max$), which was
measured by the direct method while pedaling on a cycle ergometer to the
limit, was in the range of 28-70 mℓ/min/kg. Hypoxic conditioning involved
20-min breathing hypoxic mixture with 10% O_2 daily for 5 days. Minute
volume ($\dot{V}_E$) was recorded using a modified VEB MLW (GDR) volumeter; gas analysis
was performed on an MX62-02 mass spectrometer. Gas exchange was determined
after Douglas-Haldane; sensitivity to hypoxia was assessed by the rebreathing

method with CO_2 uptake. Blood for analysis was drawn from the cubital vein before conditioning and after 5-fold delivery of the hypoxic load. Isolated and eluted erythrocytes were hemolyzed by means of freezing and thawing. The LDH isozyme spectrum in the hemolysate was determined by electrophoresis on agar [12]. Since activity of anaerobic LDH fractions is entirely restored 1 h after thawing [7], electrophoresis was performed 1 h after rapid thawing of the samples. Electrophoresis conditions: 1 h 20 min duration, 240-250 mA current, voltage 120 V. The amount of hemolysate decanted per well was 0.02 ml. Electrophoresis conditions and specimen staining were the same before and after the hypoxic load, since erythrocytes were kept frozen, then electrophoresis was performed simultaneously on agar [3]. Densitometry was performed on a Karl Zeiss Jena (GDR) densitometer. The obtained data were submitted to processing by methods of variation statistics.

Results and Discussion

The results of these studies revealed that hypoxia conditioning elicits changes in both overall LDH activity in a hemolysate of human blood and its isozyme spectrum. The overall parameter of total enzyme activity increased reliably by 34%. This change was attributable to increase in activity of all fractions of the enzyme; however, reliable changes were recorded only with respect to aerobic fractions (29% change in LDH-1 + LDH-2). The relative increase in anerobic fractions (LDH-4 + LDH-5) constituted a mean of 121%, but the significant individual variations of these changes do not enable us to refer reliably to similarity of this reaction.

Analysis of changes in percentage of each fraction revealed that there was virtually no change in share of aerobic fractions in total LDH (2.7% decrease), while the aerobic fractions showed more than 2-fold increase.

Figure 1.
Change in minute volume ($\dot{V}_E$) and oxygen uptake ($\dot{V}_{O_2}$) during nypoxia conditioning (% of baseline)
X-axis, sequential number of conditioning treatment

Thus, 5-fold exposure to acute hypoxia is associated with an increase in the integral indicator of total LDH activity, as well as redistribution of percentage of each fraction in the direction of increase in share of anaerobic fractions. These changes are combined with a change in nature of response of the respiratory system to hypoxia: as conditioning progresses there is a decrease in ventilation increment in a stable state, as well as less marked decline in oxygen uptake ($\dot{V}_{O_2}$; Figure 1). The coefficient of oxygen utilization increases with hypoxia from 22.1 ± 1.8 on the 1st day to 29.4 ± 2.1 ml/l on the last day (P<0.05). We demonstrated a reliable correlation between changes in oxygen uptake with hypoxia and change in LDH activity: the greater the increase in total LDH fractions during hypoxia conditioning, the less the decline of $\dot{V}_{O_2}$ when breathing the hypoxic mixture ($r = -0.58$; P<0.05).
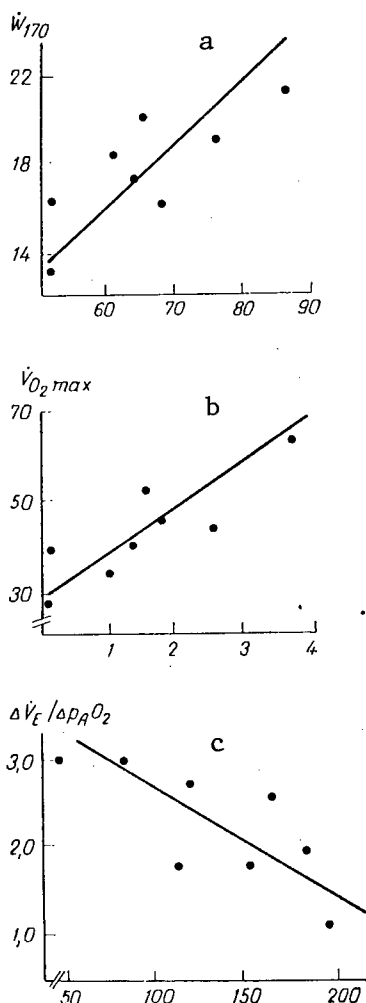
Figure 2.
Correlation between physical work capacity (a; $r = 0.73$), maximum oxygen uptake (b; $r = 0.86$), sensitivity to hypoxia (c; $r = 0.69$) and LDH isozyme composition in red cells

X-axis: a) number of aerobic fractions of LDH (arbitrary units) before hypoxia conditioning

b) number of anaerobic LDH fractions (arbitrary units) before hypoxia conditioning

c) change in number of anaerobic LDH fractions (% of baseline) as a result of hypoxia conditioning

Y-axis: a) $\dot{W}_{170}$ (kg-m/kg)

b) $\dot{V}_{O_2}$ max (ml/min/kg)

c) $\Delta\dot{V}_E/\Delta p\ O_2$ (ml/min/kg/gPa)

The wide individual variability of changes in anaerobic fractions under the effect of hypoxia, occurring as a result of inspiration of 10% hypoxic mixture, prompted us to investigate the link between these parameters and others characterizing constitutional reactivity. These studies revealed a significant relationship between baseline parameters of LDH acgivity and level of physical work capacity, as well as maximum aerobic output: higher activity of both the total enzyme ($r = 0.61$; P<0.01) and of its different fractions is observed in subjects with higher $\dot{V}_{O2max}$ (Figure (Figure 2a, b).

During hypoxia conditioning, the subjects with high levels of physical work capacity showed a less marked increase in activity of aerobic LDH fractions ($r = -071$ [sic]; P<0.001) and more marked increase in share of anaerobic fractions ($r = 0.61$). An inverse relationship was found between ventilation sensitivity to hypoxia and increase in anaerobic fractions as a result of conditioning ($r = -0.69$; P<0.01) (Figure 2c), which is indicative of differences in individual strategy of adaptation of the subjects.

The demonstrated changes in activity of LDH isozyme fractions in human erythrocytes during hypoxia conditioning are in agreement with the results of experiments with animals [6, 8, 10, 17]. During adaptation to hypoxia there is activation of glycolysis and reactions of the pentose phosphate cycle, the link between which is effected via LDH and the NAD·H$_2$ and NAD system [1, 13]. In spite of the fact that pyruvate oxidation is the principal route of its conversion in Krebs' cycle, the LDH reaction determines to a significant fate the subsequent fate of pyruvate formed as a result of glycolysis; pyruvate, in turn, controls in the form of feedback (just like tricarboxylic acids) the isozyme composition of LDH. Thus, an excessive amount of pyruvate inhibits formation of LDH-1, whereas LDH-5 is not inhibited by pyruvate [15, 18]. A reliable increase was demonstrated in anaerobic fractions of LDH in the blood of neonates who

had sustained asphyxia, in the presence of various diseases associated with tissular hypoxia, hypoxic-hypercapnic factors [4, 15]. As it was established, LDH-5 is demonstrable in young forms of erythrocytes, for example with activation of erythropoietic function as a result of a hypoxic stimulus, whereas in old erythrocytes circulating in the bloodstream or discharged from the reservoir under the effect of hypoxia, LDH-1 is typically present [15]. The relative increase in LDH-1 and LDH-2 activity demonstrated in our studies is apparently attributable to increase in total amount of erythrocytes as a result of their discharge from the reservoir, whereas activation of LDH-4 and LDH-5 fractions is due to increase in young forms of erythrocytes flushed out of bone marrow.

Direct activation of synthesis of LDH monomers, which is observed in the presence of hypoxia [16, 18, 20], and direct regulation of the last stage of enzyme synthesis, i.e., assembly of enzymatically active tetramers of some fraction from the already synthesized subunits [2], may also be causes of change in LDH isozyme composition. The opinion has been expounded that regulation of these processes is effected by means of repression and regulation of activity of the corresponding A or B loci of genes that encode synthesis of polypeptide chains of LDH subunits [9]. Since maximum aerobic output in man is a strictly genetically determined trait [5], it can be assumed that changes in LDH isozyme composition (for example, those demonstrated in our studies in response to a hypoxic stimulus) depend to some extent on his genotype. Thus, in our studies, we demonstrated a correlation between changes in isozume composition of erythrocyte LDH, degree of sensitivity to hypoxia and maximum oxygen uptake, which are traits that are determined, to a significant extent, genetically [11].

As shown by the studies, along with evaluation of the percentage of each LDH fraction, it is expedient to calculate the integral index of overall LDH activity [3], which offers additional opportunities to assess its involvement in the process of adaptation to acute hypoxia.

Thus, repeated exposure to acute hypoxia causes an increase in the integral index of overall LDH activity in a hemolysate of human red blood cells and redistribution of the percentile proportion of fractions in the direction of increase in share of anaerobic ones. Greater overall activity of this enzyme and its different fractions, as well as greater increase in anaerobic fractions during hypoxia conditioning against the background of a diminished ventilation response to the hypoxic stimulus, are observed in individuals with a high baseline level of physical work capacity.

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